GAMIFIED CNC PROGRAMMING THROUGH LOG-BASED SIMULATION: A DATA-DRIVEN FRAMEWORK FOR VOCATIONAL ENGINEERING LEARNING

Dian Julianto Wahyudi
Universitas Negeri Malang, Indonesia
dian.wahyudi.ft@um.ac.id

Johan Wayan Dika
Universitas Nahdlatul Ulama Blitar, Indonesia
johanwayandika@gmail.com

Adhan Efendi
National Chin-Yi University of Technology, Taichung, Taiwan
adhan1991@gm.student.ncut.edu.tw

Abstract
This study evaluates the effectiveness of integrating gamification into CNC programming instruction using the CAMotics simulator. Twenty-eight Mechanical Engineering students participated in a four-week gamified intervention combining leveling, points, badges, instant feedback, and leaderboards. Data were collected through pre/post-tests, motivation questionnaires, and simulator log metrics (time-on-task, error rate, and revisions). Results show significant improvements in post-test scores ($p < 0.001$) and substantial reductions in completion time and syntax errors (Cohen's $d > 2.8$). Motivation scores also increased, with intrinsic motivation positively correlating with technical performance. Theoretically, this study extends technology-enhanced learning by positioning simulator log data as a performance-based evaluation framework for vocational gamification design. Although the study was conducted without a control group, the findings provide preliminary evidence of the effectiveness of gamified simulator learning in vocational engineering contexts. Practically, it offers an evidence-driven model for integrating digital gamified learning into mechanical engineering education.

Keywords: Gamification, CNC milling, simulator-based learning, engineering education, CAMotics, performance metrics, skill acquisition

INTRODUCTION

The learning of Computer Numerical Control (CNC) milling is an integral component of the mechanical engineering education curriculum, as it encompasses mastery of fundamental aspects such as G-code comprehension, toolpath strategy development, and machine operational safety[1][2][3]. The development of these skills requires hands-on practice using real CNC machines in laboratory settings. However, limitations such as restricted lab time availability, high operational costs, and potential safety risks pose significant challenges to optimizing the learning process[4][5][6]. In response to these challenges, computer-based CNC simulators offer an effective alternative solution[7][8]. These simulators allow students to safely, flexibly, and cost-effectively grasp the operational principles of CNC machines. A study by [9][10] demonstrated that virtual CNC training systems can enhance both the effectiveness and efficiency of learning compared to conventional approaches. While simulators address the logistical and safety challenges of CNC training, they often lack motivational elements. To overcome this, gamification provides an engaging framework that complements the procedural rigor of simulator-based learning.

With the advancement of educational technology, gamification is defined as the application of game-like elements such as points, badges, levels, real-time feedback, and leaderboards in non-game contexts, has become increasingly relevant in boosting students' motivation, engagement, and learning outcomes[11][12]. Although widely applied in various educational domains, the implementation of gamification in simulator-based technical learning environments, particularly for CNC training, remains limited. Existing studies tend to emphasize learners' perceptions through subjective questionnaires and rarely adopt

[1] Rubani, S. N. K., Tukiman, N. N., Hamzah, N., Zakaria, N., & Ariffin, A, Development of Simulation-Based Learning: G-Code Programming for CNC Milling in Vocational Colleges. *Innovative Teaching and Learning Journal, 8*(2) 2024, 173–182.
[2] Latif, K., Adam, A., Yusof, Y., & Kadir, A. Z. A, A review of G code, STEP, STEP-NC, and open architecture control technologies based embedded CNC systems. *The International Journal of Advanced Manufacturing Technology, 114*(9) 2021, 2549–2566.
[3] Camacho-Betancourt, A., Basinger, K. L., & Rivero, I. V, Cutting Edge Education: Exploring Continuous Improvement in CNC Training Across Academic Levels. In *2025 ASEE Annual Conference & Exposition*, 2025.
[4] Kurniawan E.D, Nopriyanti, N., Hermawan, R., & Yanti, P. I, Pengembangan Modul Pembelajaran Berbasis Stem Pada Materi CNC Milling Simulator. *Jurnal Pendidikan Teknik Mesin, 10(*2) 2023, 204–216.
[5] Tushe, M., Lybesha, L., & Rrushi, M, Impact of Laboratory Hours on Improving Practical Skills and Clinical Understanding of General Nursing Students at Aldent University. *Journal of Health Science and Reports*, SRC/JHS, 2025-103.
[6] Xu, C., Guo, L., Wang, K., Yang, T., Feng, Y., Wang, H., & Fu, G, Current challenges of university laboratory: Characteristics of human factors and safety management system deficiencies based on accident statistics. *Journal of Safety Research, 86*, (2023) 318–335.
[7] Nathanael, D., Mosialos, S., Vosniakos, G. C., & Tsagkas, V, Development and evaluation of a virtual reality training system based on cognitive task analysis: The case of CNC tool length offsetting. *Human Factors and Ergonomics in Manufacturing & Service Industries, 26*(1) 2016, 52–67.
[8] Lu, T. C., Chen, R. C., Hsuen, G. E., & Huang, S. W. (2018). A study on CNC machine training based on virtual reality technology. In *International Conference on Intelligent Information Hiding and Multimedia Signal Processing*, 2018, 257–265.
[9] Liu, P., & Zhu, C.-F, A virtual CNC training system. In *Simulations, Serious Games and Their Applications*, 167–182) 2014. Springer.
[10] Ibarra Kwick, J. M., Hernández-Uribe, Ó., Cárdenas-Robledo, L. A., & Luque-Morales, R. A, Extended Reality Applications for CNC Machine Training: A Systematic Review. *Multimodal Technologies and Interaction, 8(*9) 2024, 80.
[11] Huang, W. H. Y., & Soman, D. (2013). Gamification of education. *Behavioural Economics in Action, 29*(4) 2019, 37–45.
[12] Toda, A. M., Klock, A. C., Oliveira, W., Palomino, P. T., Rodrigues, L., Shi, L., ..., & Cristea, A. I, Analysing gamification elements in educational environments using an existing Gamification taxonomy. *Smart Learning Environments, 6(*1) 2019, 1–14.

objective metric-based assessments such as task completion time (time-on-task) or error rates[13].

Previous research indicates that CNC simulators can generally enhance students' technical competencies. For instance, [14]showed that virtual machining helps students better understand CNC programming, toolpath planning, and error control. Locally, [15]also reported significant improvements in students' conceptual understanding and learning outcomes using CNC simulators. However, most of these studies have yet to incorporate gamification systems comprehensively within realistic simulation environments. This is noteworthy considering that, in vocational education contexts, gamification has been proven to substantially increase learning motivation[16]. Furthermore, few studies have evaluated the effectiveness of gamification using observation-based and objective technical data.

Based on this context, the present study identifies two major research gaps that merit further exploration. First, there is a lack of integrated gamification systems within realistic CNC simulators, such as CAMotics, that offer toolpath visualization and user activity logging capabilities. Second, the limited use of data-driven evaluative metrics, such as time-on-task and error rate, in assessing both skill acquisition and sustained learning motivation. Performance metrics in this study refer specifically to system-recorded indicators such as task completion time, syntax error frequency, and file revision counts. Skill acquisition encompasses both cognitive understanding of G-code syntax and procedural competence in toolpath development. In addressing these gaps, this study aims to develop and evaluate a gamification system integrated into the CAMotics CNC simulator platform. The contributions of this research include: (1) integrating gamification elements such as points, levels, badges, real-time feedback, and leaderboards into the CAMotics system to create an immersive and competitive learning experience; (2) evaluating learning effectiveness using technical metrics automatically recorded through system log data, including time-on-task and error rate, to complement conventional methods such as pre/post-tests and motivation questionnaires; and (3) employing a medium-term quantitative approach to measure the impact of gamification on G-code mastery and toolpath strategy development over 4–6 weeks using statistical analyses, such as paired t-tests and correlation tests.

Through this approach, the study is expected to offer theoretical and practical contributions to developing digital technology-based engineering learning models, particularly in adaptive, data-driven vocational mechanical engineering education contexts. From a pedagogical perspective, the integration of gamification and simulator-based learning aligns with the principles of *Self-Determination Theory (SDT)* (Deci & Ryan, 2000), which emphasizes autonomy, competence, and relatedness as core drivers of motivation. In this context, points, badges, and leaderboards serve as mechanisms that reinforce perceived competence, while real-time feedback supports autonomy in technical exploration.

[13] Abizar, H., Fawaid, M., Nurhaji, S., & Pambudi, A. R, Efektivitas pembelajaran praktik CNC menggunakan Swansoft simulator pada keaktifan belajar siswa. *Taman Vokasi, 8*(1) 2020, 1–8,. https://doi.org/10.30738/jtv.v8i1.7619

[14] Kruea-In, N., & Thongperm, O, Teaching of science process skills in Thai contexts: Status, supports and obstacles. *Procedia-Social and Behavioral Sciences, 141*, 2014, 1324–1329.

[15] Kurniawan, I. R, Efektivitas aplikasi simulator CNC bubut terhadap hasil belajar siswa kelas XI di SMK Negeri 3 Yogyakarta. *Jurnal Pendidikan Vokasional Teknik Mesin, 10*(2) 2022, 153–158.

[16] Clarke, R., Peel, D., Arnab, S., Morini, L., Keegan, H., & Wood, O, EscapED: A framework for creating educational escape rooms and interactive games for higher/further education. *International Journal of Serious Games, 7(*3) 2020, 41–60. https://doi.org/10.17083/ijsg.v7i3.403

Furthermore, the use of log-based performance metrics contributes to the emerging framework of *Learning Analytics in Vocational Education* (Ferguson, 2019), enabling data-informed instructional improvement.

RESEARCH METHODS

Design and Research Approach

This study employs a quantitative approach using a pre-experimental design of the one-group pre-test post-test type. This design was selected to enable an empirical evaluation of the impact of integrating gamification elements into the CAMotics simulator on three key indicators: improvement in learning outcomes, acquisition of technical skills, and mid-term learning motivation. This design is considered appropriate for objectively measuring changes in student performance before and after the intervention (gamification), using both test instruments and observational data from simulator activities.

Research Participants

This study involved 28 fourth-semester students from the Mechanical Engineering Study Program at the State University of Malang enrolled in the CNC Programming course. The sampling technique employed a purposive sampling approach with the following inclusion criteria: (a) having completed the Basic Machining course, and (b) possessing fundamental experience in G-code programming and using computer-based simulation software.

Research Instruments

To collect data triangulatively, three types of instruments were used as follows:

• **Written Test (Pre-test and Post-test):**

This test consists of 15 multiple-choice questions and one case study to measure understanding of G-code syntax, machine coordinate systems, and toolpath strategies. The instrument's content validity was reviewed by two CNC machining experts and one technical learning technology specialist. This test evaluates students' cognitive ability improvement before and after the intervention.

• **Data Logs from the CAMotics Simulator:**

The CAMotics simulator automatically records user activities, which are then analyzed based on four main variables: task completion time (time-on-task), number of G-code syntax errors, number of collision/overcut incidents, and frequency of simulation file corrections. This data provides an objective quantitative overview of students' technical performance.

• **Learning Motivation Questionnaire:**

This instrument was developed based on the intrinsic and extrinsic motivation model proposed by[17], consisting of 10 statement items rated on a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree). The questionnaire assesses students' perceptions and motivational drive throughout the intervention process.

[17] Su, C. H., & Cheng, C. H, A mobile gamification learning system for improving the learning motivation and achievements. *Journal of Computer Assisted Learning*, 31(3) 2015, 268–286. https://doi.org/10.1007/978-981-4560-32-0_11

Gamification Intervention Design

Gamification in this study was designed based on the conceptual framework by [18], which defines gamification as the use of game design elements in non-game contexts to enhance user experience and engagement. The intervention was conducted over four weeks, consisting of eight face-to-face sessions in the computer laboratory. Students were asked to complete a series of CNC simulation modules based on CAMotics, which had been integrated with the following gamification elements:

Table 1. Implementation of Gamification Elements in the CAMotics-Based CNC Simulation Modules

Gamification Element	Implementation in the Module
Leveling	Students complete 4 complexity levels, ranging from 2D to 3D milling
Points	Awarded for completing simulations without syntax errors
Instant Feedback	CAMotics provides immediate notifications when errors occur
Badge	Awarded if students complete the simulation perfectly on the first attempt
Leaderboard	Student scores and rankings are updated and displayed weekly

All activities were monitored by two teaching assistants to ensure consistency in implementation and validity of the process.

Data Analysis Techniques

Data analysis was conducted quantitatively using SPSS software. The analysis procedures included:

- A paired t-test was used to examine the significance of differences between pre-test and post-test scores.
- Descriptive analysis of CAMotics simulator logs to observe changes in completion time and technical errors from session to session.
- Pearson correlation test to identify the relationship between students' learning motivation levels and their technical performance during the intervention.

All analyses were performed at a significance level of $\alpha = 0.05$.

Validity, Reliability, and Research Ethics

Content validity of all research instruments was obtained through expert judgment from three specialists in manufacturing engineering and technical education. Meanwhile, the reliability of the motivation questionnaire was tested using Cronbach's Alpha coefficient, with $\alpha > 0.70$ indicating acceptable reliability. The entire research process was conducted in accordance with ethical principles, including obtaining written informed consent from participants, ensuring data anonymity, and granting participants the right to withdraw at any time during the study. The sample size (N = 28) was limited due to course enrollment constraints. This may restrict the generalizability of findings beyond similar vocational contexts. Although the one-group pre-test–post-test design limits causal inference, it was intentionally chosen to allow exploratory evaluation in a real instructional setting without disrupting the existing course structure. Future studies are recommended to adopt quasi-

[18] Deterding, S., Dixon, D., Khaled, R., & Nacke, L. (2011). From Game Design Elements to Gamefulness: Defining "Gamification." *Proceedings of the 15th International Academic MindTrek Conference*, 9–15. https://doi.org/10.1145/2181037.2181040

experimental or mixed-method designs to validate the causal relationship between gamification elements and performance outcomes while maintaining ecological validity.

RESEARCH RESULTS AND DISCUSSION

Pre-test and Post-test Results

A total of 28 students enrolled in the CNC Programming course participated in the pre-test and post-test, which consisted of multiple-choice questions and case studies related to G-code programming, as illustrated in Figure 1. Statistical analysis using the paired sample t-test showed a significant increase in test scores after the intervention. The mean pre-test score of 62.4 (SD = 9.5) increased to 76.8 (SD = 8.1) in the post-test, with a significance value of $p < 0.001$. This improvement indicates that integrating gamification elements into CAMotics-based simulator learning effectively enhanced students' understanding of G-code syntax, machine coordinate systems, and toolpath logic. These findings align with previous studies by [11] [12], demonstrating that gamification in engineering education can significantly improve concept retention.

Figure 1. Students are engaging in CAMotics-based CNC Programming simulation in the computer laboratory as part of the gamified learning intervention

Observational Data Analysis from Simulator Logs

In addition to cognitive test results, observational data from CAMotics simulator activity logs were used to measure students' technical performance. Four main indicators were analyzed: simulation completion time, number of G-code syntax errors, collision/overcut incidents, and frequency of file revisions. Statistical tests revealed that the average simulation time significantly decreased from 196.2 seconds to 141.4 seconds ($p < 0.001$), while syntax errors dropped from 4.3 to 1.6 errors per student ($p < 0.001$). Effectiveness analysis using Cohen's d showed values of 3.92 for simulation time and 2.85 for syntax errors, classified as "very large effects" according to Cohen (1988). These results indicate that the gamification intervention not only improved task efficiency but also enhanced technical accuracy and precision in code writing.

Table 2. Summary of Pre- and Post-Test Performance Indicators

Variable	Pre-test Mean (SD)	Post-test Mean (SD)	p-value	Effect Size (d)
Test Score	62.4 (9.5)	76.8 (8.1)	< 0.001	2.85
Syntax Error	4.3 (1.2)	1.6 (0.9)	< 0.001	2.85
Simulation Time (s)	196.2	141.4	< 0.001	3.92

The table summarizes the statistical improvements observed in both cognitive (test scores) and technical performance (syntax errors and simulation time), clearly indicating the large magnitude of effects resulting from the gamified intervention.

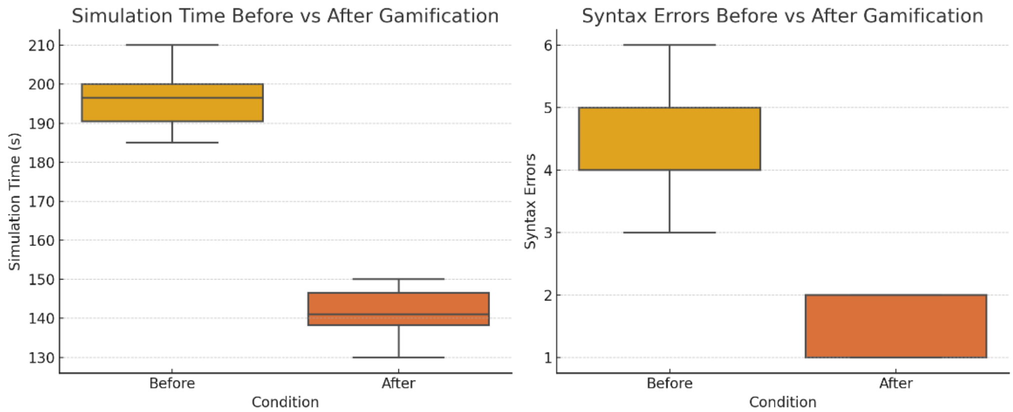

Figure 2. Comparison of simulation time and syntax error counts before and after gamification.

Figure 2 visualizes data using boxplots, showing a narrowing range of score distribution and a shift in the median toward better performance, indicating consistent improvements across nearly all participants. This finding supports [12]'s argument that gamification designed with instant feedback can promote mastery learning strategies. Furthermore, data-log-based evaluative approaches contribute significantly to improving the validity of learning outcomes, surpassing limitations of perception- or self-report-based measurements commonly used in gamification studies.

Learning Motivation Questionnaire Analysis

Analysis of the learning motivation questionnaire, using a 1–5 Likert scale, revealed increases across all measured dimensions. Mean intrinsic motivation scores rose from 3.5 to 4.2, extrinsic motivation from 3.1 to 3.9, and cognitive engagement from 3.2 to 4.3. This increase indicates that the integration of game elements such as badges, leaderboards, and leveling successfully created a more challenging, engaging, and enjoyable learning environment for students. These findings are consistent with [16], who showed that gamification can stimulate active learning when game elements are directly linked to activities and technical achievements.

Correlation Between Motivation and Technical Performance

Pearson correlation tests revealed a significant positive relationship between intrinsic motivation and students' technical performance. Higher intrinsic motivation scores were associated with shorter simulation completion times ($r = –0.64$; $p < 0.01$) and fewer G-code file revisions ($r = –0.52$; $p < 0.05$). These negative correlations indicate that internally motivated students tend to complete simulations faster and with fewer errors. This underscores the important role of affective factors, particularly motivation, in supporting procedural skill improvement in simulation-based technical learning.

General Discussion

Overall, the results of this study demonstrate that applying gamification in CAMotics-based CNC programming learning significantly improves students' cognitive, technical, and motivational performance. This is illustrated in Figure 3, which shows some students observing and directly interacting with CNC machines after completing the simulation. Systematic integration of game elements encouraged more active learning engagement and provided a more adaptive learning experience through real-time feedback. However, it is essential to consider that if not thoughtfully designed, gamification can also lead to unintended consequences such as reduced intrinsic motivation or superficial engagement, as cautioned by [19]. Moreover, the use of observational data from simulator logs enriches the evaluation approach with objective evidence of students' technical skill progress, which has been less explored in previous gamification studies[20].

Figure 3. Students verifying programming results by directly operating the CNC machine after completing the simulation on CAMotics software.

Figure 3. illustrates the transfer of learning from virtual to real CNC practice, showing students verifying simulation outputs on physical machines. This supports the constructivist notion of situated learning, where digital practice enhances real-world procedural competence. The significant reduction in completion time and number of errors indicates that students not only grasp conceptual aspects but can also implement this knowledge as measurable procedural skills. This highlights the importance of using observational metrics in technical learning evaluation, as recommended by [21] and opens opportunities for replicating this approach in other technical education contexts.

The integration of gamified elements with simulator log analytics demonstrates a dual-impact mechanism in vocational education: (1) *motivational reinforcement* through challenge and feedback loops, and (2) *cognitive scaffolding* through iterative, data-tracked performance. These findings suggest that future CNC programming instruction can adopt a data-driven gamified learning model (DGLM), where students' cognitive and procedural progress is continuously monitored through simulator data. This approach contributes to the

[19] Almeida, C., Kalinowski, M., Uchôa, A., & Feijó, B, Negative effects of gamification in education software: Systematic mapping and practitioner perceptions. *Information and Software Technology*, *156*, 107142, 2023.
[20] Koç, D., Seçkin, A. Ç., & Satı, Z. E, Evaluation of Participant Success in Gamified Drone Training Simulator Using Brain Signals and Key Logs. *Brain Sciences*, *11*(8) 2021, 1024.
[21] Bergin, S., & Reilly, R, The influence of motivation and comfort-level on learning to program. *Proceedings of the 17th Workshop of the Psychology of Programming Interest Group* , 2005 293–304. https://ppig.org/files/2005-PPIG-16th-bergin.pdf

broader discourse on technology-enhanced vocational learning, supporting adaptive feedback, personalized instruction, and competency-based assessment.

CONCLUSION

This study demonstrates that integrating gamification into CAMotics-based CNC programming learning significantly improves students' academic and technical performance. Using a quasi-experimental approach with a one-group pre-test post-test design, the study found significant improvements in learning outcomes, simulation completion efficiency, and reductions in syntax errors ($p < 0.001$). Effect size analysis using Cohen's d yielded values of 3.92 for simulation time and 2.85 for syntax errors, categorized as very large effects. These findings indicate that gamified learning is not only effective in enhancing student motivation but also capable of objectively promoting procedural skill development.

The primary contribution of this study lies in utilizing simulator log data as a valid, performance-based evaluative instrument. Furthermore, this research proves that gamification can be practically and effectively implemented within vocational technical education contexts, particularly in CNC programming, which has traditionally relied on conventional methods.

Beyond its empirical significance, this study contributes to the theoretical development of data-driven gamification in vocational education. It provides an evaluative framework that bridges gamified learning design and objective simulator analytics. Strategically, the findings support the integration of digital gamified modules into vocational curricula to promote self-regulated, performance-based technical learning aligned with Industry 4.0 competencies.

This study validates the effectiveness of gamified simulator learning in improving both conceptual and procedural competencies in CNC programming. Despite its limited sample and single-group design, it demonstrates the pedagogical potential of integrating log-based analytics in vocational training. Future research should compare different gamification models and expand data analytics for adaptive feedback in digital vocational curricula.

REFERENCES

Abizar, H., Fawaid, M., Nurhaji, S., & Pambudi, A. R, Efektivitas pembelajaran praktik CNC menggunakan Swansoft simulator pada keaktifan belajar siswa. *Taman Vokasi*, *8*(1) 2020, 1–8,. https://doi.org/10.30738/jtv.v8i1.7619

Almeida, C., Kalinowski, M., Uchôa, A., & Feijó, B, Negative effects of gamification in education software: Systematic mapping and practitioner perceptions. *Information and Software Technology*, *156*, 107142, 2023.

Bergin, S., & Reilly, R, The influence of motivation and comfort-level on learning to program. *Proceedings of the 17th Workshop of the Psychology of Programming Interest Group* , 2005 293–304. https://ppig.org/files/2005-PPIG-16th-bergin.pdf

Camacho-Betancourt, A., Basinger, K. L., & Rivero, I. V, Cutting Edge Education: Exploring Continuous Improvement in CNC Training Across Academic Levels. *In 2025 ASEE Annual Conference & Exposition*, 2025.

Clarke, R., Peel, D., Arnab, S., Morini, L., Keegan, H., & Wood, O, EscapED: A framework for creating educational escape rooms and interactive games for higher/further education. *International Journal of Serious Games*, *7*(3) 2020, 41–60. https://doi.org/10.17083/ijsg.v7i3.403

Deci, E. L., & Ryan, R. M, *The "What" and "Why" of Goal Pursuits: Human Needs and the Self-Determination of Behavior.* Psychological Inquiry, 11(4) 2000, 227–268.

Deterding, S., Dixon, D., Khaled, R., & Nacke, L. (2011). From Game Design Elements to Gamefulness: Defining "Gamification." *Proceedings of the 15th International Academic MindTrek Conference*, 9–15. https://doi.org/10.1145/2181037.2181040

Ferguson, R, *Learning analytics in vocational education and training.* Journal of Learning Analytics, 6(2) 2019, 27–39.

Hamari, J., Koivisto, J., & Sarsa, H, *Does Gamification Work? – A Literature Review of Empirical Studies on Gamification.* HICSS 47, 3025–3034.

Huang, W. H. Y., & Soman, D. (2013). Gamification of education. *Behavioural Economics in Action*, *29*(4) 2019, 37–45.

Ibarra Kwick, J. M., Hernández-Uribe, Ó., Cárdenas-Robledo, L. A., & Luque-Morales, R. A, Extended Reality Applications for CNC Machine Training: A Systematic Review. *Multimodal Technologies and Interaction*, *8*(9) 2024, 80.

Kapp, K. M, *The gamification of learning and instruction: Game-based methods and strategies for training and education.* Wiley, 2012.

Koç, D., Seçkin, A. Ç., & Satı, Z. E, Evaluation of Participant Success in Gamified Drone Training Simulator Using Brain Signals and Key Logs. *Brain Sciences*, *11*(8) 2021, 1024.

Kruea-In, N., & Thongperm, O, Teaching of science process skills in Thai contexts: Status, supports and obstacles. *Procedia-Social and Behavioral Sciences*, *141*, 2014, 1324–1329.

Kurniawan E.D, Nopriyanti, N., Hermawan, R., & Yanti, P. I, Pengembangan Modul Pembelajaran Berbasis Stem Pada Materi CNC Milling Simulator. *Jurnal Pendidikan Teknik Mesin*, *10*(2) 2023, 204–216.

Kurniawan, I. R, Efektivitas aplikasi simulator CNC bubut terhadap hasil belajar siswa kelas XI di SMK Negeri 3 Yogyakarta. *Jurnal Pendidikan Vokasional Teknik Mesin*, *10*(2) 2022, 153–158.

Latif, K., Adam, A., Yusof, Y., & Kadir, A. Z. A, A review of G code, STEP, STEP-NC, and open architecture control technologies based embedded CNC systems. *The International Journal of Advanced Manufacturing Technology*, *114*(9) 2021, 2549–2566.

Liu, P., & Zhu, C.-F, A virtual CNC training system. In *Simulations, Serious Games and Their Applications*, 167–182) 2014. Springer.

Lu, T. C., Chen, R. C., Hsuen, G. E., & Huang, S. W. (2018). A study on CNC machine training based on virtual reality technology. *In International Conference on Intelligent Information Hiding and Multimedia Signal Processing*, 2018, 257–265.

Nathanael, D., Mosialos, S., Vosniakos, G. C., & Tsagkas, V, Development and evaluation of a virtual reality training system based on cognitive task analysis: The case of CNC tool length offsetting. *Human Factors and Ergonomics in Manufacturing & Service*

Industries, *26*(1) 2016, 52–67.

Rubani, S. N. K., Tukiman, N. N., Hamzah, N., Zakaria, N., & Ariffin, A, Development of Simulation-Based Learning: G-Code Programming for CNC Milling in Vocational Colleges. *Innovative Teaching and Learning Journal*, *8*(2) 2024, 173–182.

Su, C. H., & Cheng, C. H, A mobile gamification learning system for improving the learning motivation and achievements. *Journal of Computer Assisted Learning*, *31*(3) 2015, 268–286. https://doi.org/10.1007/978-981-4560-32-0_11

Toda, A. M., Klock, A. C., Oliveira, W., Palomino, P. T., Rodrigues, L., Shi, L., ..., & Cristea, A. I, Analysing gamification elements in educational environments using an existing Gamification taxonomy. *Smart Learning Environments*, *6*(1) 2019, 1–14.

Tushe, M., Lybesha, L., & Rrushi, M, Impact of Laboratory Hours on Improving Practical Skills and Clinical Understanding of General Nursing Students at Aldent University. *Journal of Health Science and Reports*, SRC/JHS, 2025-103.

Xu, C., Guo, L., Wang, K., Yang, T., Feng, Y., Wang, H., & Fu, G, Current challenges of university laboratory: Characteristics of human factors and safety management system deficiencies based on accident statistics. *Journal of Safety Research*, *86*, (2023) 318–335.