

Tailored Gamification in Manual Assembly: System Implementation and Study Design for Long-Term Evaluation

Johannes Hug and Jörg Wollert

University of Applied Sciences Aachen, Germany

hug@fh-aachen.de

wollert@fh-aachen.de

Abstract: The potential of gamified didactic scenarios in promoting intrinsic motivation, readiness to learn, and long-term efficiency improvements has been extensively confirmed in numerous studies. While there is abundant research on gamification in educational contexts and digital learning environments, its transferability to industrial contexts—particularly manual assembly processes—remains insufficiently explored. Employees in manufacturing environments characterized by short product life cycles, single-piece production, and increasing product variants continuously engage in agile adaptation and learning processes, making adaptively designed gamified assistance systems highly promising. Traditional rigid assistance systems initially improve process reliability and facilitate standardized training phases, yet they can lead to increased cognitive strain, reduced autonomy, and declining motivation over the long term. Intensive, rigid assistance in particular may provoke cognitive overload due to constant information overload and restricted freedom of action. Our preliminary studies further indicate that, although gamified elements initially boost performance, sustained use may similarly result in increased stress and diminished autonomy. To address these challenges, an adaptive assistance system incorporating a flexible gamification platform was developed and practically implemented within a medium-sized enterprise (SME) specializing in the assembly of safety-critical components. This system enables employees to individually select and activate gamification elements such as point systems, levels, badges, and leaderboards. Furthermore, an adaptive information provision mechanism was integrated, dynamically reducing information complexity and density, thereby promoting targeted learning processes and sustainably mitigating cognitive strain. For comprehensive evaluation of the system's long-term effects on employee motivation, autonomy, process quality, and efficiency, a mixed-methods approach combining both quantitative and qualitative techniques was adopted. Objective interaction data (e.g., task completion times, error rates) are continuously captured through real-time behavioural logging, while subjective aspects (system usability, perceived cognitive load, motivation, technology acceptance, and perceived autonomy) are assessed through standardized Likert-scale questionnaires. This paper describes in detail the conceptual framework, practical implementation, and study design. It systematically explores how individually tailored gamification influences employee motivation, autonomy, process quality, and efficiency improvements within manual assembly tasks.

Keywords: Tailored gamification, Human factors, Industry 5.0, Intrinsic motivation, Cognitive ergonomics

1. Introduction

Industrial manufacturing is increasingly characterized by growing challenges from shortened product life cycles, rising product and process variability, and volatile global markets (Schuh et al. 2022). As a result, companies are compelled to continuously increase the degree of digitalization in their production systems and integrate innovative technologies efficiently into existing structures (Zhong et al. 2017). However, technological modernization alone is insufficient to address the escalating complexity of industrial value creation; instead, a holistic approach to flexibility is required to systematically incorporate both technological and human resources (Liao et al. 2017). Building on this need for human-centred flexibility, gamification – the deliberate use of game-design elements in non-game contexts (Deterding et al. 2011) – has emerged as a promising strategy to foster worker motivation, reduce cognitive load, and stimulate adaptive skill development in industrial settings (Sailer and Homner 2020; Oliveira et al. 2023). The necessity to dynamically adapt production units to fluctuating requirements makes agile and reconfigurable production systems indispensable (ElMaraghy 2005). Modular plant architectures, digital networking, and data-driven control concepts form the technological foundation of this new production paradigm. However, technological agility alone is inadequate if human labour, as a flexible and adaptive resource, is not simultaneously integrated into system design (Gorecky et al. 2014). Unlike automated systems, human operators possess the unique ability to make situational decisions under uncertainty, flexibly assume various tasks, and intuitively respond to unforeseen changes (Akhtar and Carlo 2024). This universal deployability renders humans an indispensable element of agile production systems. However, this flexibility is not without risk: the constant adaptation to new processes, technologies, and task profiles can lead to cognitive overload, elevated stress levels, and long-term declines in motivation (Wollter Bergman et al. 2021). Safeguarding the sustainable performance of human workers in highly dynamic production environments thus necessitates innovative support concepts beyond traditional, static assistance systems. Conventional systems, which provide standardized recommendations for action, quickly reach their limits under high variability and uncertainty (Longo et al. 2017; Villani et al. 2017). Consequently, adaptive assistance systems

are gaining importance, offering dynamic support tailored to individual skills, experience levels, and situational demands (Yigitbas et al. 2023). An auspicious approach to designing such adaptive systems is the targeted integration of gamification elements. Using game-like mechanisms such as points, badges, or challenges can systematically enhance motivation and learning effectiveness, provided that these elements are implemented in an evidence-based and context-sensitive manner (Smiderle et al. 2020; Rodrigues et al. 2022). Recent studies show that gamification yields the most sustainable effects when individual differences in motivation, cognitive load, and learning styles are carefully considered (Oliveira et al. 2023). Against this backdrop, the present paper explores the interplay between humans and adaptive technology within flexible and agile production systems. Particular emphasis is placed on the role of gamified assistance systems as key technologies for promoting adaptability, motivation, and cognitive relief in dynamic manufacturing environments.

2. Literature Review: Assistance Systems and Gamification

The evolution of assistance systems in industrial assembly has been driven by the need to increase efficiency, reduce errors, and manage the growing complexity of production tasks. Over the past years, numerous technological approaches have been developed and evaluated to support human workers during manual assembly processes.

2.1 Evolution of Assistance Systems

In recent years, traditional paper-based work instructions have increasingly been replaced by digital work instructions (DWIs). Empirical studies demonstrate that DWIs can significantly reduce task completion times and perceived cognitive workload compared to paper-based instructions, thereby improving assembly efficiency and quality (Eversberg and Lambrecht 2023). In laboratory studies, object-based, context-enriched 3D instructions have demonstrated a reduction in task completion time by 14.94%, accompanied by a substantial decrease in perceived cognitive load (Alessa et al. 2023). Projection technologies, which visualize work steps directly onto the workpiece, have led to a 50% reduction in error rates during assembly tasks, as demonstrated in large-scale virtual experiments (Pietschmann et al. 2023). Pick-to-light (P2L) systems, combined with Poka-Yoke logic, have demonstrated significant improvements in assembly performance. Field studies report up to 20–35% reductions in assembly times and approximately 35% decreases in error rates (Trojanowska et al. 2023). Augmented reality (AR) technologies further expand this approach: the use of AR smart glasses enables hands-free and immediate interaction with digital instructions. Empirical studies involving 188 learners indicate high usability and a reduced cognitive load, thereby freeing cognitive resources that can be redirected toward learning (Warkentin et al. 2025).

It is important to note, however, that many of these studies primarily focus on learning phases or the support of novice users. For experienced workers, digital assistance systems can potentially have counterproductive effects.

2.2 Limitations of Static Assistance Systems

While digital assistance systems have proven valuable in supporting novice users during learning phases, their effectiveness becomes increasingly questionable when applied to experienced workers in dynamic production environments. Studies suggest that for experts, such systems can even be counterproductive (Funk 2016). As demonstrated by the expertise reversal effect, instructional support that is beneficial to novices may become redundant or distracting for advanced users, leading to increased cognitive load and longer task execution times (Kalyuga et al. 2003). In addition to performance drawbacks, static assistance systems raise motivational concerns. According to the Self-Determination Theory, autonomy is a fundamental psychological need that fosters intrinsic motivation (Gagné and Deci 2005). When workers are locked into step-by-step instructions without flexibility or choice, their perceived autonomy may be diminished—which in turn appears to be associated with reduced engagement and potentially lower learning transfer. Beyond motivation, such systems may discourage deeper cognitive processing. Users might adopt copy-paste behaviour, mechanically following instructions rather than internalizing procedures or reflecting on process logic. This could inhibit procedural learning and reduce adaptive expertise (Branzetti et al. 2022). Moreover, prolonged reliance on external support can lead to skill atrophy. Instead of fostering competence, static systems may create dependence, which becomes particularly problematic in cases where improvisation, troubleshooting, or system failures demand independent action. In such cases, assistance may not only fail to help—it can actively undermine performance (Dr.A.Shaji George et al. 2024). Finally, overly prescriptive guidance structures can limit opportunities for creative problem-solving and bottom-up process optimization. In lean production philosophies, continuous improvement thrives on worker autonomy and reflection. Assistance systems that restrict deviation from

predefined paths may suppress innovation and hinder the iterative refinement of work practices (Costa et al. 2019). Given these limitations, there is growing recognition that next-generation assistance systems must move beyond standardized, one-size-fits-all paradigms. Instead, they should support both procedural correctness and individual agency, allowing experienced users to maintain control, engage cognitively, and contribute to continuous improvement. Given these findings, it is increasingly recognized that future assistance systems must support procedural correctness and preserve and enhance user autonomy, cognitive engagement, and skill development. From the perspective of Industry 5.0, there is an apparent demand for human-centred, adaptive assistance concepts that dynamically align with workers' evolving capabilities and situational needs (Moenck et al. 2025).

2.3 Advantages of Gamified Learning Scenarios

In response to the limitations of static assistance systems, research in educational psychology and instructional design has increasingly focused on gamified learning environments. Gamification—the strategic use of game design elements in non-game contexts—aims to enhance motivation, engagement, and cognitive processing during learning activities (Deterding et al. 2011). Multiple meta-analyses demonstrate that gamified interventions can significantly improve learning outcomes by promoting voluntary engagement, self-directed exploration, and deeper cognitive investment (Sailer and Homner 2020; Subhash and Cudney 2018). Game elements such as points, badges, leaderboards, and challenges foster goal setting, provide immediate feedback and sustain user motivation over more extended learning periods (Kim and Castelli 2021). Moreover, gamified learning scenarios have been shown to support the development of autonomy and competence—two critical components of intrinsic motivation as described by self-determination theory (Ryan et al. 2006). Studies report that learners in gamified environments often exhibit higher persistence, greater task enjoyment, and improved problem-solving performance compared to conventional instructional settings (Sailer and Homner 2020). Thus, gamification offers promising mechanisms to address precisely those shortcomings that static assistance systems impose over time: maintaining engagement, promoting adaptive learning, and sustaining motivation even under repetitive or complex task conditions.

2.4 Emergence of Gamified Assistance Systems

Building on these insights, integrating gamification principles into industrial assistance systems has emerged as a promising approach. Gamified assistance systems aim to combine procedural guidance with motivational enhancement, offering structured yet engaging task support.

By embedding elements such as performance feedback, progression tracking, goal challenges, and adaptive difficulty levels within digital or augmented work instructions, these systems seek to maintain user engagement, support skill acquisition, and reduce cognitive fatigue during repetitive or highly complex assembly tasks (Ulmer et al. 2024).

3. Research Methodology

The development of an adaptive, gamified assistance system for high-variability manual production environments necessitates a modular and flexible technological foundation. In agile production contexts, where product variants, process steps, and operator profiles change frequently, system architectures must be capable of rapid adaptation without extensive reprogramming or system downtime.

To address these requirements, three core technological prerequisites were identified:

3.1 System Architecture and Technological Implementation

3.1.1 Modular software architecture

A scalable and component-based backend capable of orchestrating diverse workflows through standardized information objects. This architecture ensures that new work steps, components, or product variants can be integrated dynamically without impacting system stability.

3.1.2 No-Code platform for process design

A no-code environment is essential to enable fast and decentralized workflow adaptation by production planners and shopfloor personnel. It allows non-programmers to define, modify, and deploy work instructions independently, accelerating innovation cycles and reducing dependency on IT specialists.

3.1.3 Modular gamification platform

A modular gamification backend is required to flexibly configure motivational mechanisms. This backend enables the activation, adjustment, or deactivation of elements such as progress bars, scoring systems, and reward structures without code-level changes.

3.2 Information Provision in the Adaptive Assistance System

Effective human-centered assistance systems must deliver information in a way that aligns with their users' cognitive needs, skills, and situational demands. This requires a modular, scalable, and context-sensitive approach to information delivery in highly variable manual production environments. The presented system organizes instructional content into six standardized information classes, each supporting a specific cognitive and procedural requirement:

1. Tool Information: Identification and visualization of the tools necessary for the current work step.
2. Component Information: Context-sensitive allocation of required parts and materials.
3. Skill Information: Instruction for operating specialized fixtures or equipment correctly.
4. Process Flow Information: Animated visualizations (GIFs or videos) depicting ideal procedural sequences to strengthen procedural memory and enhance operational reliability.
5. Quality Control Information: Visualization of target states and typical defect patterns to guide manual inspection processes.
6. Inspection Result Recording: Structured input of inspection results and quality feedback by operators.

All information objects are created within a cloud-based no-code environment and can be flexibly reused across various workflows ("flows").

Process descriptions are fully declarative, multilingual, and scalable, enabling rapid adaptation to new products, processes, or user needs without requiring system reprogramming. Information is delivered via displays and interactively linked to plug-and-play devices such as P2L systems, camera-based verification modules, and barcode scanners. This integration ensures that users receive context-relevant information directly at the point of need, minimizing cognitive search effort and maximizing procedural focus.

3.3 Rule-Based Information Granularity

While structured and accessible information provision forms the basis for effective task support, static information density may hinder autonomy development and motivation over time, particularly for experienced workers. To mitigate this, the system employs an adaptive model of information granularity based on an eight-level support framework. Table 1 shows the granularity of the framework, which defines a stepwise reduction of available instructional support:

Table 1: Reduction of information density

Support Level	Available Information	Reduction compared to previous level
Level 1	Full Information: Tools, Components, Skill, GIF/Video, P2L (Tools/Components), Quality Control	-
Level 2	Tools, Components, GIF/Video P2L (Tools/Components), Quality Control	No Information how to use the assembly fixture (Skill)
Level 3	P2L (Tools/Components), GIF/Video, Quality Control	No further Information about necessary Tools/Components than P2L
Level 4	P2L (Components), GIF/Video, Quality Control	No P2L for Tools
Level 5	P2L (Tools), GIF/Video, Quality Control	No P2L for Components
Level 6	GIF/Video, Quality Control	No P2L
Level 7	P2L (Tools/Components, Quality Control)	No GIF/Video
Level 8	Quality Control	Full Autonomy

Critically, users are not automatically transitioned between support levels based on system performance evaluation. Instead, users maintain full autonomy to choose their current support level and task difficulty. This preserves intrinsic motivation, respects user competence, and aligns with principles of self-determined learning. Performance-related data is still collected passively to provide feedback and create opportunities for

motivational triggers. However, advancement is not imposed — users are encouraged, but not required, to explore and master higher autonomy levels. Figure 1 shows the User-Interface (UI) of the assistance system (A) and the manual workstation with the assistance-system and gamification-platform (B).

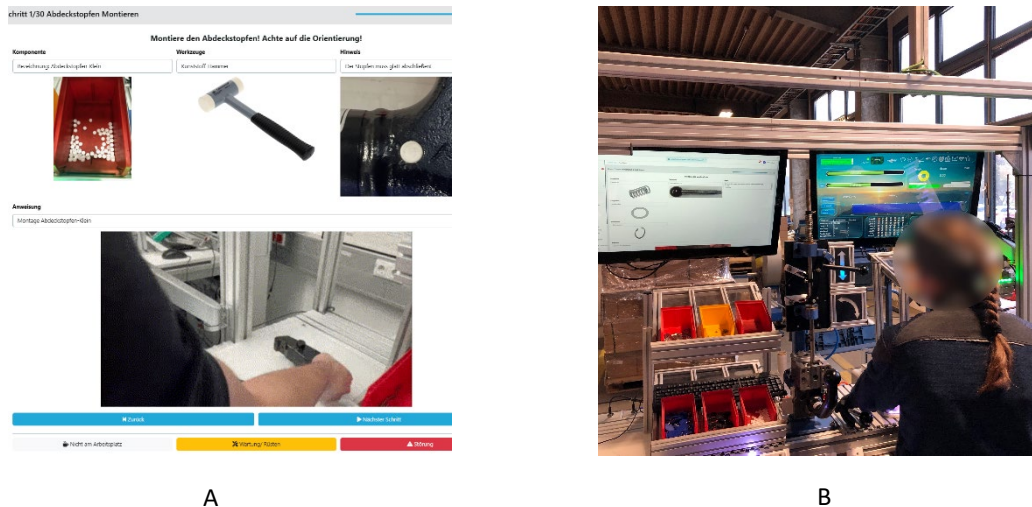


Figure 1: (A) Assistance-System-Interface Level 1. (B) Assembly-Station with Assistance- & Gamification-Platform

3.4 User Interaction Analysis

In order to objectively assess the cognitive and procedural demands associated with individual task steps, the system systematically captures key metrics of user interaction during task execution. The primary aim of this data collection is to analyze which phases of task performance consume significant time resources, thereby identifying potential cognitive bottlenecks, procedural inefficiencies, or error-prone stages.

Each work step is segmented into three distinct temporal phases:

- *Interpretation Time*: The time span from the presentation of a task instruction to the user's correct interaction with the relevant tool or component. This phase reflects the effort required for task comprehension, decision-making, and cognitive orientation.
- *Execution Time*: The net duration required to correctly complete the task using the intended tools and materials, serving as an indicator of procedural fluency and operational efficiency.
- *Correction Time*: The cumulative time spent on erroneous interactions (e.g., selection of incorrect tools) until a successful correction is achieved, either autonomously or through system feedback. This metric provides insight into adaptive behaviour, error recovery capabilities, and process robustness.

Real-time data capture is enabled through integrated sensor technologies, including P2L verification, camera-based selection monitoring, and software-side event logging. Collected data are anonymized in compliance with applicable data protection regulations and stored for subsequent aggregated analysis. By evaluating the distribution and trends of these time metrics across users and task types, the system enables the identification of critical phases where cognitive load, procedural complexity, or decision uncertainty are particularly pronounced. Such insights form the empirical basis for subsequent system adaptations, ergonomic improvements, and the refinement of motivational support mechanisms.

3.5 Integration of Gamification

The systematic analysis of user interaction metrics reveals clear patterns of cognitive load distribution, procedural efficiency, and error resilience across different task phases and support levels. However, while these insights enable a nuanced understanding of individual and system-level performance dynamics, they do not, by themselves, ensure voluntary engagement with higher autonomy stages or increase task difficulty. Given that users retain full autonomy over their selected support level and task configuration, fostering continuous competence development requires more than the mere availability of performance feedback. It necessitates an active motivational architecture that encourages users to challenge themselves, explore more demanding task variants, and deliberately reduce informational support over time. To address this challenge, the presented system integrates a comprehensive gamification framework to motivate users to pursue voluntary skill advancement intrinsically. Rather than enforcing progression through prescriptive mechanisms, the system

leverages game-inspired incentives to transform autonomous upskilling into a rewarding and self-directed experience. The following section details the structural elements of this gamification approach and its role in promoting sustainable engagement, intrinsic motivation, and long-term competence development within the adaptive assistance environment.

3.6 Core Mechanics of Gamified Motivation and Progression

The developed system structures voluntary skill progression by providing a defined set of challenge scenarios.

Each of the eight Information Support Levels, representing varying degrees of instructional density, combines seven Difficulty Stages that modulate the allowable execution time for a complete product assembly.

Thus, the system generates a total of 56 distinct challenge scenarios, each uniquely defined by:

- the amount of instructional support provided, and
- the allowed total time for completing a full assembly cycle.

Each Support Level is assigned A benchmark assembly time based on its informational density.

The Difficulty Stage adjusts this benchmark by a defined factor, ranging from:

- Very Easy: benchmark \times 1.25 (extended time)
- Additional 5 Sub-States
- Insane down to benchmark \times 0.75 (tightest time constraint)

Throughout the assembly process, users are accompanied by a paced timer, transparently communicating the remaining time for completing the current product assembly. This mechanism transforms each assembly cycle into a discrete challenge unit, linking performance to informational support and time pressure—without external enforcement. For each successfully completed scenario—defined as the correct and timely assembly of a full product at the selected Support Level and Difficulty Stage—users earn a unique Badge.

Consequently, 56 Badges are achievable across the system. Figure 2 shows the correlation of information-density and the benchmark.

Badges fulfil two parallel functions:

- They provide symbolic recognition of task mastery under specific cognitive and procedural demands.
- They award virtual currency (Coins), scaled based on the selected Support Level and Difficulty Stage:
- Higher autonomy levels (lower informational support) and stricter time constraints yield exponentially greater Coin rewards.

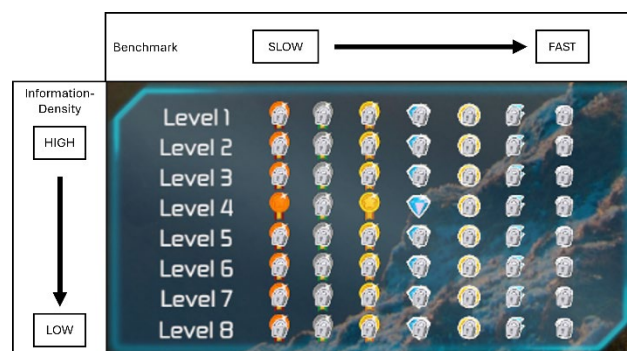


Figure 2: Badge-System with Relation between Information-Density and Benchmark

Accumulated Coins can be spent within the integrated Shop System to unlock personalization features, such as:

- Custom visual backgrounds for the UI,
- Animation effects are triggered upon successful assembly cycles.

To maintain long-term engagement, the shop employs a non-linear pricing structure:

Higher-tier customization options require exponentially greater Coin investments.

To accelerate progression after mastering multiple challenges, the system offers a Prestige Cycle:

- Users can voluntarily reset their Badge collection after meeting predefined Badge and Score thresholds.
- Their Prestige Level increases, resulting in a multiplicative boost to all future Coin earnings.
- This cyclical mechanism fosters repeated voluntary skill expansion, encouraging sustained system engagement and iterative personal growth.

As illustrated in Figure 3, users who regularly activate the Prestige mechanic gain access to significantly more coins over time, allowing them to afford new shop items more frequently. While non-Prestige users accumulate currency at a constant rate, resulting in increasing delays between item unlocks, Prestige users benefit from a reset-and-multiplier logic that keeps item acquisition intervals consistently short.

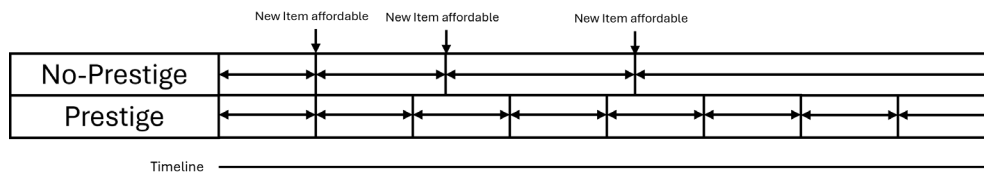


Figure 3: Illustration of progression dynamics in the gamification system. Users who activate the prestige mechanic benefit from accelerated coin accumulation, allowing more frequent buying of shop items

4. Further Work

A dual-layered strategy captures behaviour and perception. The system logs each assembly cycle’s support level, difficulty stage, interpretation, execution and correction times, plus error events, enabling longitudinal analyses. Perception is polled at scheduled UI prompts with validated five-point Likert scales: the System Usability Scale (SUS; Brooke 1996), key items from the Technology Acceptance Model (TAM; Davis 1989), NASA-TLX for cognitive load (Hart & Staveland 1988), and motivation/engagement via the User Engagement Scale (UES; O’Brien & Toms 2010). Optional free-text comments add qualitative depth. This protocol yields a fine-grained view of how operators use and experience the adaptive gamified assistance system. Data collection is ongoing; results will be reported separately.

5. Conclusion

The system presented in this work addresses the central challenges of highly variable assembly environments through the targeted combination of a modular, adaptive assistance framework and a fully configurable gamification platform. Introducing an eight-level Support Model enables the systematic adjustment of information density to users’ individual development trajectories, fostering both process reliability and autonomous skill acquisition. The dynamic regulation of support intensity helps prevent cognitive overload and monotony, facilitating a gradual promotion of user autonomy within the assembly process. The integrated gamification platform addresses key motivational factors through individualized progress visualizations, reward mechanisms (Coins, Badges), and customizable user experiences. In particular, implementing a Prestige Mode enables a cyclical motivational structure that encourages both repetition and deepening of acquired competencies. The complete digitalization of process descriptions via a no-code framework allows complex assembly workflows to be created, adapted, and deployed flexibly without requiring advanced programming skills. The strict separation of content, logic, and presentation ensures high scalability and international applicability. The comprehensive system logging architecture and the integration of standardized evaluation instruments provide a robust methodological basis for an evidence-based assessment of system effects. By systematically capturing both objective performance metrics and subjective user experiences, the approach enables a holistic analysis that goes beyond purely operational indicators. Overall, the developed system represents a promising foundation for the next generation of adaptive, human-centered assistance systems in industrial manufacturing. It contributes to the operationalization of Industry 5.0 concepts by designing technological support systems that are flexible, individualized, and intrinsically motivating.

6. Outlook and Further Work

Building on the presented concept, several extensions and deepening activities are planned for the next project phase. A multi-month field study will be conducted under near-production conditions to evaluate the system further. The aim is to generate insights into the long-term effects on efficiency, quality, user autonomy, and motivation through detailed longitudinal analyses. Particular attention will be paid to the impact of different

gamification configurations and support level progressions. In parallel, the development of an AI-based recommendation system is being prepared. Based on aggregated usage data, this system will be designed to generate individualized optimization suggestions for support levels, difficulty stages, and information densities. This will enable adaptive responses to learning progress, performance changes, or shifts in user motivation. Another focus area is the integration of additional sensor-based interaction channels, such as wearable devices for real-time strain measurement or AR-interfaces for dynamic context support. The framework will evolve into an open platform in the long term, facilitating cross-domain experimentation with adaptive assistance concepts. The goal is to generate transferable insights applicable to various industrial and non-industrial contexts — including maintenance, education, and healthcare. Through this systematic expansion, the project aspires to make a substantive contribution to the future design of human-technology interactions, oriented not only toward productivity goals but equally toward human learning capacity, motivation, and sustainable competence development.

Acknowledgements

This research was funded by the German Federal Ministry of Education and Research (BMBF) under grant number 02L21B500 and administrated by the Project Management Agency Karlsruhe (PTKA).

Ethic clearance declaration: This publication describes the development and intended evaluation of a gamified assistance system. No empirical user data were collected at this stage. Therefore, no formal ethics approval was required for the study setup presented.

AI declaration: During the preparation of this article, AI-based tools were utilized to assist in the filtering and evaluation of literature sources. The authors confirm that all scientific interpretations, evaluations, conclusions, and manuscript writing were performed independently without substantive AI-generated content.

References

- Akhtar, Saleem/Carlo, Amina (2024). The Role of Human Factors in Dynamic Scheduling for Agile Manufacturing Environments. <https://doi.org/10.13140/RG.2.2.17530.20161>.
- Alessa, Faisal M./Alhaag, Mohammed H./Al-Harkan, Ibrahim M./Ramadan, Mohamed Z./Alqahtani, Fahad M. (2023). A Neurophysiological Evaluation of Cognitive Load during Augmented Reality Interactions in Various Industrial Maintenance and Assembly Tasks. *Sensors* (Basel, Switzerland) 23 (18). <https://doi.org/10.3390/s23187698>.
- Branzetti, Jeremy/Gisondi, Michael A./Hopson, Laura R./Regan, Linda (2022). Adaptive expertise: The optimal outcome of emergency medicine training. *AEM education and training* 6 (2), e10731. <https://doi.org/10.1002/aet2.10731>.
- Brooke, John. SUS - A quick and dirty usability scale. *Usability Eval Ind* 189 (194), 4–7.
- Costa, Federica/Lispi, Leonardo/Staudacher, Alberto Portioli/Rossini, Matteo/Kundu, Kaustav/Cifone, Fabiana Dafne (2019). How to foster Sustainable Continuous Improvement: A cause-effect relations map of Lean soft practices. *Operations Research Perspectives* 6, 100091. <https://doi.org/10.1016/j.orp.2018.100091>.
- Davis, Fred D. (1989). Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. *MIS Quarterly* 13 (3), 319. <https://doi.org/10.2307/249008>.
- Deterding, Sebastian/Tan, Desney/Khaled, Rilla/Nacke, Lennart E. (2011). *Gamification: Toward a Definition*. New York, NY, ACM.
- Dr.A.Shaji George/Dr.T. Baskar/Dr. P. Balaji Srikanth (2024). The Erosion of Cognitive Skills in the Technological Age: How Reliance on Technology Impacts Critical Thinking, Problem-Solving, and Creativity. <https://doi.org/10.5281/zenodo.11671150>.
- ElMaraghy, Hoda A. (2005). Flexible and reconfigurable manufacturing systems paradigms. *International Journal of Flexible Manufacturing Systems* 17 (4), 261–276. <https://doi.org/10.1007/s10696-006-9028-7>.
- Eversberg, Leon/Lambrecht, Jens (2023). Evaluating digital work instructions with augmented reality versus paper-based documents for manual, object-specific repair tasks in a case study with experienced workers. *The International Journal of Advanced Manufacturing Technology* 127 (3-4), 1859–1871. <https://doi.org/10.1007/s00170-023-11313-4>.
- Funk, Markus (2016). *Augmented Reality at the Workplace. A Context-Aware Assistive System using In-Situ Projection*. Dissertation. Universität Stuttgart.
- Gagné, Marylène/Deci, Edward L. (2005). Self-determination theory and work motivation. *Journal of Organizational Behavior* 26 (4), 331–362. <https://doi.org/10.1002/job.322>.
- Gorecky, Dominic/Schmitt, Mathias/Loskyll, Matthias/Zuhlke, Detlef (2014). Human-machine-interaction in the industry 4.0 era. In: 2014 12th IEEE International Conference on Industrial Informatics (INDIN), 2014 12th IEEE International Conference on Industrial Informatics (INDIN), Porto Alegre RS, Brazil, 27.07.2014 - 30.07.2014. IEEE, 289–294.
- Hart, Sandra G./Staveland, Lowell E. (1988). Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. In: P. A. Hancock/N. Meshkati (Eds.). *Human Mental Workload*. s.l., Elsevier textbooks, 139–183.
- Jerusalem, Matthias/Schwarzer, Ralf (1995). *PsycTESTS Dataset*.

- Kalyuga, Slava/Ayres, Paul/Chandler, Paul/Sweller, John (2003). The Expertise Reversal Effect. *Educational Psychologist* 38 (1), 23–31. https://doi.org/10.1207/s15326985ep3801_4.
- Kim, Jihoon/Castelli, Darla M. (2021). Effects of Gamification on Behavioral Change in Education: A Meta-Analysis. *International journal of environmental research and public health* 18 (7). <https://doi.org/10.3390/ijerph18073550>.
- Liao, Yongxin/Deschamps, Fernando/Loures, Eduardo de Freitas Rocha/Ramos, Luiz Felipe Pierin (2017). Past, present and future of Industry 4.0 - a systematic literature review and research agenda proposal. *International Journal of Production Research* 55 (12), 3609–3629. <https://doi.org/10.1080/00207543.2017.1308576>.
- Longo, Francesco/Nicoletti, Letizia/Padovano, Antonio (2017). Smart operators in industry 4.0: A human-centered approach to enhance operators' capabilities and competencies within the new smart factory context. <https://doi.org/10.48550/arXiv.2206.00104>.
- Moenck, Keno/Koch, Julian/Rath, Jan-Erik/Büsch, Lukas/Gierecker, Johann/Kähler, Falko/Kalscheuer, Florian/Masuhr, Christian/Kipping, Johann/Prünke, Philipp/Schoepflin, Daniel/Eschen, Henrik/Wulff, Lukas Antonio/Rodeck, Rebecca/Wende, Gerko/Gomse, Martin/Schüppstuhl, Thorsten (2025). Industry 5.0 in aircraft production and MRO: challenges and opportunities. *CEAS Aeronautical Journal*. <https://doi.org/10.1007/s13272-025-00832-3>.
- Moshagen, Morten/Thielsch, Meinold T. (2010). Facets of visual aesthetics. *International Journal of Human-Computer Studies* 68 (10), 689–709. <https://doi.org/10.1016/j.ijhcs.2010.05.006>.
- O'Brien, Heather L./Toms, Elaine G. (2010). The development and evaluation of a survey to measure user engagement. *Journal of the American Society for Information Science and Technology* 61 (1), 50–69. <https://doi.org/10.1002/asi.21229>.
- Oliveira, Wilk/Hamari, Juho/Shi, Lei/Toda, Armando M./Rodrigues, Luiz/Palomino, Paula T./Isotani, Seiji (2023). Tailored gamification in education: A literature review and future agenda. *Education and Information Technologies* 28 (1), 373–406. <https://doi.org/10.1007/s10639-022-11122-4>.
- Pietschmann, Leon/Zuercher, Paul-David/Bubík, Erik/Chen, Zhutian/Pfister, Hanspeter/Bohné, Thomas (2023). Quantifying the Impact of XR Visual Guidance on User Performance Using a Large-Scale Virtual Assembly Experiment. <https://doi.org/10.48550/arXiv.2308.03390>.
- Rodrigues, Luiz/Toda, Armando M./Oliveira, Wilk/Palomino, Paula T./Vassileva, Julita/Isotani, Seiji (2022). Automating Gamification Personalization: To the User and Beyond. <https://doi.org/10.48550/arXiv.2101.05718>.
- Ryan, Richard M./Deci, Edward L./Grolnick, Wendy S./La Guardia, Jennifer G. (2006). The Significance of Autonomy and Autonomy Support in Psychological Development and Psychopathology. In: Dante Cicchetti/Donald J. Cohen (Eds.). *Developmental Psychopathology. Volume One: Theory and Method*. Hoboken, NJ, John Wiley & Sons, 795–849.
- Sailer, Michael/Homner, Lisa (2020). The Gamification of Learning: a Meta-analysis. *Educational Psychology Review* 32 (1), 77–112. <https://doi.org/10.1007/s10648-019-09498-w>.
- Schuh, Günther/Riesener, Michael/Gützlaff, Andreas/Dölle, Christian/Schmitz, Seth/Ays, Johanna/Wlecke, Shari/Tittel, Jonas/Liu, Yuan (2022). Industry 4.0: Agile Development and Production with Internet of Production. In: Walter Frenz (Ed.). *Handbook Industry 4.0*. Berlin, Heidelberg, Springer Berlin Heidelberg, 367–390.
- Smiderle, Rodrigo/Rigo, Sandro José/Marques, Leonardo B./Peçanha de Miranda Coelho, Jorge Arthur/Jaques, Patricia A. (2020). The impact of gamification on students' learning, engagement and behavior based on their personality traits. *Smart Learning Environments* 7 (1). <https://doi.org/10.1186/s40561-019-0098-x>.
- Subhash, Sujit/Cudney, Elizabeth A. (2018). Gamified learning in higher education: A systematic review of the literature. *Computers in Human Behavior* 87, 192–206. <https://doi.org/10.1016/j.chb.2018.05.028>.
- Trojanowska, Justyna/Husár, Jozef/Hrehová, Stella/Knapcikova, Lucia (2023). Poka Yoke in Smart Production Systems with Pick to Light Implementation to Increase Efficiency: A Study.
- Ulmer, Jessica/Braun, Sebastian/Cheng, Chi-Tsun/Wollert, Jörg (2024). Gamified Assistance System: Effects of a Level and Feedback System on Work Performance, System Usability, and Motivation.
- Villani, Valeria/Sabattini, Lorenzo/Czerniak, Julia N./Mertens, Alexander/Vogel-Heuser, Birgit/Fantuzzi, Cesare (2017). Towards Modern Inclusive Factories: A Methodology for the Development of Smart Adaptive Human-Machine Interfaces. <https://doi.org/10.48550/arXiv.1706.08467>.
- Warkentin, Max/Altmeyer, Kristin/Liang, Yajie/Steinmacher, Bermann/Gränz, Barbara/Lichtenberger, Andreas/Küchemann, Stefan/Kuhn, Jochen/Hoyer, Christoph (2025). Hands-on Experiment Supported by Augmented Reality Smartglasses for Learning the Lorentz Force. <https://doi.org/10.48550/arXiv.2502.06421>.
- Wollert Bergman, Matilda/Berlin, Cecilia/Babapour Chafi, Maral/Falck, Ann-Christine/Örtengren, Roland (2021). Cognitive Ergonomics of Assembly Work from a Job Demands-Resources Perspective: Three Qualitative Case Studies. *International journal of environmental research and public health* 18 (23). <https://doi.org/10.3390/ijerph182312282>.
- Yigitbas, Enes/Sauer, Stefan/Engels, Gregor (2023). Self-Adaptive Digital Assistance Systems for Work 4.0. In: Birgit Vogel-Heuser/Manuel Wimmer (Eds.). *Digital Transformation*. Berlin, Heidelberg, Springer Berlin Heidelberg, 475–496.
- Zhong, Ray Y./Xu, Xun/Klotz, Eberhard/Newman, Stephen T. (2017). Intelligent Manufacturing in the Context of Industry 4.0: A Review. *Engineering* 3 (5), 616–630. <https://doi.org/10.1016/J.ENG.2017.05.015>.