Enhancing manufacturing quality through gamification: an exploratory study in collaborative assembly process

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Enhancing manufacturing quality through gamification: an exploratory study in collaborative assembly process

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STRUCTURED ABSTRACT

Purpose: This research explores an application of gamification in the manufacturing sector, with a particular focus on its potential to increase engagement, quality and productivity in collaborative assembly processes involving humans and collaborative robots (cobots).

Methodology: A preliminary case study was conducted on the gamification of a tile cutter assembly process. The study used the Octalysis framework to implement game design elements such as scoring systems, progress tracking, and real-time feedback, and evaluated their impact on the manufacturing environment.

Findings: Preliminary findings suggest that gamification elements can promote a sense of achievement and engagement among operators, similar to the experience of playing games. This increased engagement is expected to have a positive impact on product and process quality.

Practical implications: By demonstrating the feasibility of integrating gamification principles into collaborative assembly processes, this study paves the way for manufacturers to improve operational efficiency and reduce defects through enhanced operators' motivation and engagement.

Originality: This study extends the application of gamification beyond its traditional areas of digital entertainment and education to the manufacturing sector. It uniquely explores how gamification can be applied to collaborative assembly processes, showing its potential to enhance manufacturing quality and humans' well-being.

Keywords: Gamification, Process quality, Human-robot collaboration, Human Factor

Paper type: Research paper

INTRODUCTION

The integration of gamification into manufacturing processes represents a novel approach to increase operator engagement and motivation (Seaborn and Fels 2015, Keepers *et al.* 2022). This research is based on the premise that human factors such as motivation and engagement are crucial in ensuring higher quality of manufacturing outcomes and efficiency (Liu *et al.*, 2018). Using the Octalysis framework (Chou, 2015) - a comprehensive gamification design tool that introduces elements of gaming into non-gaming environments - this paper explores the potential of applying gamification to manufacturing environments, with a particular focus on human-robot collaboration (i.e., "HRC"). HRC refers to a situations in which humans and robots perform tasks together, combining their unique strengths and capabilities (Bauer *et al.*, 2008; Galin and Meshcheryakov, 2020; Gervasi *et al.*, 2020). In this collaboration, robots are designed to interact directly with humans in a shared space or to work on the same tasks, complementing each other's capabilities, thus combining the precision, strength and consistency of robots with the cognitive, problem-solving and adaptive abilities of humans, resulting in a more efficient and productive outcome (Capponi *et al.*, 2024a; Coronado *et al.*, 2022; Gervasi *et al.*, 2023). Specifically, in collaborative assembly processes humans and robots cooperate to assemble a product (Ahmed *et al.*, 2019; Bauer *et al.*, 2008; Faccio *et al.*, 2019). The need for this investigation arises from the recognition within the field of quality management that human factor in manufacturing processes is a critical aspect to ensure process quality (Kolus *et al.*, 2018; Mantura, 2008; Yung *et al.*, 2020). Despite the advances in digital technologies and automation that characterise Industry 5.0 (Maddikunta *et al.*, 2022), the challenge of maintaining high levels of operator engagement and motivation in the repetitive and monotonous assembly tasks remains a risk for the quality of the manufacturing process. In response to these challenges, this work investigates the potentialities of introducing gamification in collaborative assembly processes in order to improve operators' motivation and engagement. To this end, an exploratory case study was developed involving three operators in a gamified collaborative assembly environment. The study collected some performance metrics, including failure rates and completion times, as well as subjective measures of workload, emotional state, and intrinsic motivation. In addition, several physiological indicators of stress and fatigue were also monitored to provide a holistic view of the impact of gamification on the assembly process (Capponi *et al.*, 2024b) . To the best of authors' knowledge no previous work investigated the potential benefits of gamification analysing physiological signals. The paper is organised as follows: section 2 presents a small literature review on gamification, section 3 and 4 introduce the Octalysis framework and how it was applied in the collaborative assembly process. In section 5 the preliminary case study is provided, while in section 6 the main results are commented. Finally, section 7 summarises the main findings.

LITERATURE REVIEW

Gamification, an innovative approach that integrates game design elements into non-game contexts, has gained significant attention across various fields for its potential to enhance user engagement, motivation, and sustainable experiences (Krath *et al.*, 2021). The concept, while initially popular in digital entertainment and education, has expanded its reach, influencing areas such as business, healthcare, and learning environments (Seaborn and Fels, 2015). A huge contribution to this field was made by Chou (2015) who proposed guidelines on how to implement good gamification design into products, workplace and lifestyle. Conceptually, gamification finds its foundation in three main psychological theories: self-determination theory (Ryan and Deci, 2000a); motivation theory (Ryan and Deci, 2000b) and flow theory (Csikszentmihalyi, 1975). Self-Determination Theory (i.e., "SDT") is a psychological theory that focuses on motivation and human personality. It identifies three innate psychological needs that are essential for growth: competence, autonomy, and relatedness (Ryan and Deci, 2000a). Competence concerns interactions with the environment and the ability to express one's abilities. Autonomy refers to choices made independently, without external constraints, in accordance with one's identity. Relatedness concerns belonging to a group in which one feels accepted. Satisfying these needs increases intrinsic motivation and leads individuals to engage in tasks in which they feel competent, autonomous and related. Motivation, as described by Ryan and Deci (Ryan and Deci, 2000b), is the drive that directs behaviour towards a goal, with varying degrees and types. On the one hand, intrinsic motivation arises from the enjoyment of the activity itself, the search for pleasure and fulfilment; on the other hand extrinsic motivation is driven by external rewards such as money or status. Cognitive appraisal theory, a sub-theory of SDT, suggests that interpersonal events that increase competence can increase intrinsic motivation. Flow theory was introduced by Csikszentmihalyi (1975) and describes an optimal state of consciousness in which individuals are fully immersed in an activity. It is characterised by total focus, goal orientation, intrinsic motivation, positive attitude and satisfaction, flow occurs when there's a balance between the level of challenge and one's own abilities. In this regard, well-designed games can induce flow, providing deep motivation and optimal performance by matching the difficulty of the game to the player's ability.

The topic of gamification has also become of interest in manufacturing very recently. There are still few attempts to adapt these concepts in industrial settings. Deterding et al. (2011) explored the historical origins of gamification and propose its definition as the use of game design elements in non-game contexts. Keepers et al. (2022) highlighted the limited scope of current research in this area and suggested directions for future research. Liu et al. (2018) showed that smartphone-based gamified work design significantly increases work motivation, satisfaction, and operational performance. Ohlig et al. (2021) presented empirical evidence on how gamified performance management systems, using gamified visualization of process metrics, increase motivation. Sochor et al. (2021) developed a framework to support the selection and implementation of gamified elements in industrial manufacturing and logistics. Klevers et al. (2016) presented the "GameLog Model" to integrate game mechanics into existing business processes. Lee et al. (2016) proposed a five-step design framework for gamification in manufacturing through a case study in an automotive assembly line. Similarly, Ulmer et al. (Ulmer *et al.*, 2020) introduced a skill-based gamification framework for manual tasks to enhance workers' engagement. In a subsequent work, the authors proposed a system of skills and levels for the individual adjustment of the complexity of the work for each step of the assembly process, using virtual reality (Ulmer *et al.*, 2023). Finally, Roh et al. (2016) explored the impact of gamification on operators' flow states and emotional experiences, linking them to intrinsic motivation. Finally, Dolly et al. (2024) analysed the effects both on productivity and on cognitive load of gamification in an industrial assembly task. However, no previous work investigated the potential benefits of gamification in assembly processes in terms of stress perceived.

APPLYING THE OCTALYSIS FRAMEWORK IN ASSEMBLY PROCESSES

The Octalysis Framework, developed by Yu-kai Chou, is a renowned tool in the field of gamification, offering a deep understanding in the application of game mechanics to non-gaming contexts. Central to the framework is the categorisation of motivational drivers into eight fundamental drives, organised in a gamification wheel that illustrates how different elements can influence human behaviour in a variety of contexts, including manufacturing. This framework is distinguished by its ability to analyse and design gamified systems through the lens of the following fundamental drives:

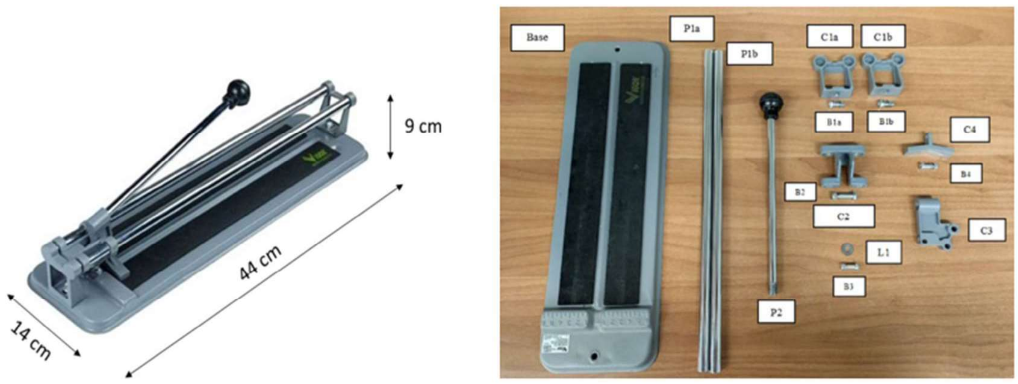
- *Epic Meaning*: it involves believing that one is part of something greater than oneself. In a work context, it means feeling that one's efforts contribute to a crucial and meaningful cause. This can be achieved by contributing to environmental sustainability or technological innovation, through storytelling or visualizing the end-use of the products being assembled can help with this. For example, posters or digital displays showing the end product in use and emphasizing its positive impact on the society could boost workers' motivation.
- *Accomplishment*: This core drive focuses on internal motivation that arises from making progress, developing skills, and achieving goals. To address this driver in industrial assembly processes, it could be useful to implement systems able to track skill development and task completion. Workers can be rewarded with badges, certifications, or levels for mastering new skills or consistently meeting production goals. This can include digital dashboards that tracks individuals or team production metrics, such as unit assembled per hours, quality scores, task times etc.
- *Empowerment*: it refers to the satisfaction of engaging in creative actions, observing the outcomes of one's creativity. It involves actively participating in a process where people have to figure things out, develop strategies and try different combinations. This could be achieved through the implementation of a digital platform where workers can submit suggestions and ideas.
- *Ownership*: this is the drive where users are motivated by the feeling of ownership, but adapting the concept of ownership to an assembly work-area is difficult. However, workers can feel a sense of ownership over their workstations or tools by providing customization options. For example, on the basis of the milestones achieved workers can be rewarded with personalised tools or the possibility to customise their workstations.
- *Social Influence*: it involves all the social elements that motivate people, such as mentorship, acceptance, social responses, and also competition and envy. It can be achieved by promoting a collaborative environment where, for example, workers, organised in teams, can earn points for their team for efficiency, safety and innovation practices.

- *Scarcity*: This phenomenon is known as the 'scarcity effect'. Scarcity and impatience can drive people to desire something more if it is rare, exclusive, or immediately unavailable. This can be implemented by introducing time-limited challenges. For example, daily or weekly challenges that require employees to achieve specific goals can be introduced, such as the most units assembled in a day.
- *Unpredictability*: This is the drive to discover what will happen next. It is the fundamental motivation behind the fascination with mysteries and the unpredictable. This keeps the work environment dynamic and engaging. For example, a system where employees can earn surprise rewards for outstanding performance, such as exceeding quality benchmarks, could be established.
- *Avoidance*: it refers to the desire to avoid negative outcomes or losses. It is characterised by the motivation to avoid punishment, danger, or potential losses. In order to avoid negative outcomes, workers should be incentivised in pursuing safety. For example, prizes and rewards could be introduced for those who maintain high safety standards.

By leveraging these drivers, the Octalysis Framework provides a robust methodology to improve engagement, productivity and overall job satisfaction in productive environments.

A GAMIFIED VERSION OF A COLLABORATIVE ASSEMBLY PROCESS

The central aim of this paper consists in investigating the feasibility of gamifying manufacturing processes. As an exploratory case study, a collaborative assembly process was considered. The case study product is a tile cutter (see Fig. 1). The assembly process of the tile cutter consists of 18 elementary tasks, which in collaborative modality are partially allocated to the human and to the cobot. Table 1 shows the list of all the parts composing the tile cutter, the related elementary task and, for HRC modality, their allocation between human and cobot. Obviously, in manual modality all tasks were performed by humans.



(a) (b)

Figure 1 – The assembled tile cutter and its main dimensions (a) and all the parts and screws composing it (b) (Gervasi *et al.*, 2024)

Table 1 – Main product characteristics and assembly process description of the tile cutter (first columns contains the list of parts and their codes and quantities, second column contains the list of the elementary task of the assembly process and the third column contains the allocation of the task between human and robot)

Product characteristics			***Assembly process***	***HRC Task allocation***	
Parts and fasteners	**Code**	**Quantities**	**Elementary task (same in manual and HRC)**	**Human**	**Cobot**
Base	Base	1	Pick and place Base		X
Lateral support	C1a/C1b	2	Pick and place C1a and C1b on Base	X	
Joint component	C2	1	Preliminary screwing C1a and C1b on Base	X	

Cutting component	C3	1	Placing the subassembly (Base+C1a+C1b) out of the assembly area		X
Blade	L1	1	Pick and place C2		X
Tile blocker	C4	1	Pick and place C3 in C2	X	
Rail rod	P1a/P1b	2	Screwing C3 and C2	X	
Handle	P2	1	Pick and place L1	X	
Bolt type 1	B1	2	Screwing L1 and C3	X	
Bolt type 2	B2	1	Pick and place C4 in C3	X	
Bolt type 3	B3	2	Screwing C4 and C3	X	
Nuts type 1	N1	2	Placing the subassembly (C2+C3+C4+L1) out of the assembly area		X
Nuts type 2	N2	1	Pick and place subassembly (Base+C1a+C1b) back in the assembly area		X
Nuts type 3	N3	2	Insert sub-assembly (C2+C3+C4+L1) in both P1a/P1b	X	
			Insert P1a/P1b in C1a/C1b	X	
			Final screwing C1a/C1b on Base	X	
			Pick and place P2	X	
			Screwing P2	X	
			Pick the final product and place out of the assembly area		X

In order to gamify the collaborative assembly processes, some gamification elements were selected, i.e., points, progress bars, multimedia feedback and suggestions. The usage of progress bars and points in the assembly process is directly linked to conventional productivity metrics (e.g., Performance Measurement Systems) such as cycle time. Furthermore, suggestions for improvement, such as optimized assembly instructions, can minimize errors and improve product quality. This reflects a direct application of quality metrics in the manufacturing process and such gamification elements align with the principles behind traditional productivity and quality measurements in manufacturing (Franceschini *et al.*, 2019; Muthiah and Huang, 2006). In detail, the main gamification elements were:

- **Points:** The scoring system is based on comparing the time taken by the operator to complete the assembly with the expected times from Table 2, which represent average execution times derived from previous laboratory experience and thus define the time taken by an 'average user'. Offering points for tasks provides immediate rewards, reinforces positive behaviour and encourages continued engagement. The assembly of the tile cutter can be broken down into four main phases: phase 1 involving the joining of the two supports with the base; phase 2 during which the cutting mechanism is assembled; phase 3 which is the final assembly of cutting mechanism, rail rods and the base leading to the final product, and phase 4 involving the pick and place of the final product in which the operator does not intervene. Each of the first three phases includes some activities performed by the operators and others by the cobot. The time spent by the operator in the three phases enables the implementation of the scoring system, as this time is compared with the benchmark values from Table 2. Specifically, the observed time T_j, where the subscript j identifies the assembly phase ($j = 1...3$), is the time between two successive digital outputs measured by the system, which includes both the component movement time used by the cobot (deterministic) and the assembly time used by the operator. Specifically, it is:

$$T_j = C_j + O_j \qquad (1)$$

where: C_j is the time related to tasks performed by the cobot while O_j represents the time of human-performed tasks. In all the phases, the times T_j are therefore compared with the reference values T_j^* predicted from Table 2, where: $T_j^* = C_j^* + O_j^*$.

Table 2 – Completion times of the four phases of the tile cutter assembly process

Phase	T_j^* **[s]**	O_j^* **[s]**	C_j^***[s]**
1	70	57	13
2	119	103	16
3	100	80	20
4	11	0	11

The scoring system provides that at each stage of the assembly a score (p_j) is assigned to the operator based on the comparison with benchmark values. Specifically, if $T_j \leq T_j^*$ then $p_j = 2$ and if $T_j > T_j^*$ then $p_j = 1$. Hence, a score of 2 is awarded if the operator performs better than the "average user", otherwise 1 point is awarded. The final score achieved by operator in the assembly of the tile cutter will be the sum of the scores achieved in the next three steps, thus $p_i = \sum_{j=1}^{3} p_j$.

- **Progress bar**: A filling progress bar is displayed on the dashboard and as each task is completed, the progress of the process can be observed. The progress of the bar corresponds to the percentage of process completion. The progress bar is completely filled when the assembly of the finished product is complete. Visualising progress with a bar helps users track their achievements and remaining tasks, giving a clear sense of progress and achievement.
- **Multimedia feedback**: it was chosen to visualise the execution times of each of the phases in order to provide the operator with feedback on her/his assembly performance in real time. In this regard, Ohlig et al. (Ohlig *et al.*, 2021) showed how a gamified information provisioning system can improve operator's motivation. Real-time feedback allows users to instantly understand their performance levels, helping them to recognise their strengths and areas for

improvement. The measurement, and visualisation, of the execution time of the assembly phases make it possible to define a performance indicator, which represents a second multimedia feedback for the operator. The basic assumption that allows the performance indicator to be defined is the distributive form of the assembly times of the various process steps. In particular, based on previous experience, it can be assumed that the execution times of phases j are normally distributed (i.e., $T_j \sim N(T_j^*; \sigma_j)$). This assumption allows a performance indicator (TPI_j) to be defined for each stage of the assembly process as follows:

$$TPI_j = \left(1 - \Phi(T_j)\right) \times 100 = \left(1 - \Phi\left(\frac{T_j - T_j^*}{\sigma_j}\right)\right) \times 100 = \left(1 - \Phi(Z_j)\right) \times 100 \quad (2)$$

In fact, it was chosen to use the anti-cumulative of T_j, as it increases as T_j decreases; therefore, it is more suitable to represent the performance of the operation.

- **Suggestions:** A virtual avatar is displayed, which during the activity provides advice to guide the operator towards the correct execution of the task, also showing illustrative images to facilitate understanding. For example, the avatar may recommend not over-tightening the screws of the supports in the first step in order to facilitate the subsequent insertion of the cutting mechanism, or show an example photo of the correct positioning of the components. Offering suggestions provides guidance and support, helping users improve their skills and performance.

Fig. 2 shows the phases of the gamified assembly process where the human operator is actually involved and the related graphical interface showing the performance of the operator.

Figure 2 – The gamified graphical interface of the collaborative assembly process

EXPERIMENTAL CASE STUDY

A small exploratory case study involving three operators was developed with the aim of assessing its feasibility and impact on user performance and engagement.

Data collection

The methodology was designed to evaluate the effectiveness of gamification by comparing objective data, such as completion time, failure rates and physiological signals with subjective data, including questionnaires and participant feedback. Specifically, the physiological measurements together with subjective data provide a comprehensive understanding of the subject's response to stress, which may provide further insights in assessing the impact of gamified environments on user experience and performance. This dual approach enabled a comprehensive analysis of the impact of the gamified system on both the efficiency of the assembly process and the overall participant experience. Expert feedback was particularly crucial in understanding the practical implications and potential improvements, providing valuable insights into the feasibility and adaptability of the gamified version in real assembly scenarios. The objective data collected were:

- Process failures: In order to evaluate the potential enhancement of process and product quality, process failures were collected both in non gamified and in gamified collaborative modality. Process failures in quality control refer to deviations or discrepancies that occur during the production process. These failures can take various forms, such as defects in the final product, inaccuracies in assembly, incorrect implementation of procedures, or misuse of materials and tools (Maisano *et al.*, 2019). In this work, process failures were organised into four categories: (i) Incorrect assembly that occurs when parts or components are assembled in the wrong order, orientation or configuration, leading to malfunction, reduced product performance or total product failure; (ii) Incorrect positioning that refers to the misplacement or misalignment of components, but, unlike incorrect assembly, at some point the operator notices and corrects; (iii) wrong input to cobot that refers to incorrect commands given to cobots by the operator, thus leading to inappropriate actions and delays; and (iv) dropping of parts that involves the accidental dropping or mishandling of components and tools during assembly.
- Completion times: The time of the assembly process was recorded, by automatically collecting the time intervals between two consecutive inputs to the cobot. This metric can be regarded as one of the proxy of the potential efficiency improvements brought by the gamification elements.
- Electro-Dermal activity (EDA) which reflects the electrical conductance of the skin. It is influenced by sweat gland activity, which is controlled by the sympathetic nervous system and is indicative of emotional arousal. EDA was analysed using continuous decomposition, distinguishing between tonic and phasic activity. Tonic activity, showing sustained

fluctuations in skin conductance, and phasic activity, reflecting immediate responses to stimuli, were measured by average skin conductance level (SCL) and skin conductance responses (SCRs), respectively (Benedek and Kaernbach, 2010).

- Heart-Rate variability (HRV) refers to the variation in time intervals between consecutive heartbeats and it was assessed as an indicator of autonomic nervous system balance and stress response. Metrics such as Root Mean Square of Successive Differences (RMSSD) and Standard Deviation of NN intervals (SDNN) were used to assess heart rate variability, providing insight into individual stress levels and recovery capabilities. Root Mean Square of Successive Differences is (i.e., RMSSD) defined as:

$$RMSSD = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N-1}(NN_{i+1} - NN_i)^2} \tag{3}$$

Where N is the number of systolic peaks in the considered time window and NN_i indicates the time interval between the systolic peak *i* and *i+1*, while "SDNN" represents the Standard Deviation of NN intervals. Generally, higher HRV values indicate a healthier, more responsive cardiovascular system, while lower values indicate potential stress or fatigue. (Kim *et al.*, 2018; Young *et al.*, 2015).

The subjective data collected were:

- NASA-TLX questionnaire: To assess subjective perception of workload in performing assembly processes, this study used the NASA TLX which is a comprehensive tool that assesses six dimensions of workload on a 0-100 scale. These dimensions include (i) mental demand that assesses the cognitive demand required from the individual by the task; (ii) physical demand that quantifies the level of physical effort required; (iii) temporal demand that assesses the perceived time pressure associated with performing the task; (iv) performance that measures the individual's perception of success and satisfaction with the results achieved; (v) effort that considers the combined mental and physical effort required to achieve a goal and (vi) frustration that measures the level of irritation, stress and annoyance experienced while performing the task. The total workload score is derived by calculating the average of these six dimensions, providing a multi-dimensional perspective on the user's perceived workload. (Hart and Staveland, 1988).

- Self-Assessment Manikin (SAM) is an image-based tool often used to measure individuals' emotional reactions to specific situations or events. This assessment has three primary dimensions: (i) Valence that identifies the emotional appeal of the experience, categorising feelings as either positive or negative; (ii) Arousal that measures the intensity of emotional activation, whether the emotion is positive or negative and (iii) Dominance that assesses the extent to which one feels in control of the event or situation (Bradley and Lang, 1994).
- Intrinsic Motivation Inventory (IMI): The Intrinsic Motivation Inventory (IMI) serves as a comprehensive tool for assessing subjective experiences related to target activities in laboratory settings, particularly in research on intrinsic motivation and self-regulation. Based on seminal work by Ryan et al. (Ryan *et al.*, 1983, 1991), the IMI provides insight through six distinct subscales: interest/enjoyment, perceived competence, effort, value/usefulness, perceived pressure and tension, and perceived choice during an activity. In this work the subscale on interest and enjoyment was exclusively considered because it was the most suitable for this type of experiment. The items of the interest/enjoyment subscale are shown in Table 3. The level of agreement for each item is evaluated on 7-point Likert scale from not at all true (1) to very true (7).

Table 3 – Item list of the Intrinsic Motivation Inventory

n	Item description
1	I enjoyed doing this activity very much
2	This activity was fun to do.
3	I thought this was a boring activity. (R)
4	This activity did not hold my attention at all. (R)
5	I would describe this activity as very interesting.
6	I thought this activity was quite enjoyable.
7	While I was doing this activity, I was thinking about how much I enjoyed it.

Experimental procedure

The case study involved three operators who performed the assembly process twice in the non gamified collaborative modality and twice in the gamified version. The three operators were researchers from the Department of Management and Industrial Engineering at the Politecnico di Torino. The experiment took place in the Mind4Lab laboratory of the Politecnico di Torino (Italy). After a short introduction to the experiment, the participant was trained to perform the collaborative assembly of the tile cutter with the UR3 cobot following the tasks listed in Table 1. Fig. 3 shows the work-area where the experiment took place. The participant then performed two repetitions of a “non gamified” modality or a “gamified” modality, which were randomly selected. At the end of performing a modality, the participant completed the Nasa-TLX, SAM and IMI questionnaires. Thus, the participant underwent two further repetitions of the remaining modality and then completed the aforementioned questionnaire again. At the end of the small experiment, unstructured and qualitative feedback was collected.t

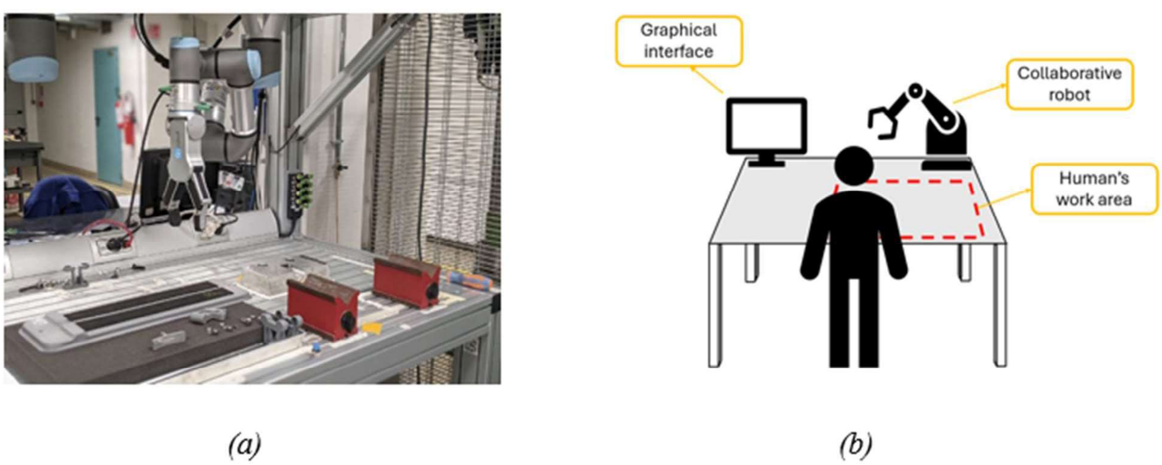


Figure 3 - The collaborative robot UR3 at the Mind4Lab of Politecnico di Torino used in the experiment (a) and a general layout of the assembly work-area (b)

RESULTS

The research was structured to compare non gamified and gamified modalities, examining both objective performance metrics (process failures and completion times); physiological signals (Average SCR and Average SCL) and subjective perceptions (Nasa-TLX, SAM and IMI).

Performance metrics

Fig. 4a shows the sum of process failures occurred in both modalities. The bar graph provides a clear visual comparison of the total number of process failures between a non gamified collaborative assembly process and its gamified version. It's clear from the graph that the gamified version of the assembly process resulted in fewer process failures than the non gamified version. The reduction in process failures in the gamified version could be attributed to increased engagement, motivation or focus of the participants, which are common benefits associated with gamification. The bar chart in Fig. 4b illustrates the comparison of average completion times in both modalities for each participant. The graph shows that for 2 out of 3 participant, the gamified version of the assembly process resulted in shorter completion times compared to the non gamified version. Considering the results of the comparison of completion times, gamification may have the potential to improve the efficiency of collaborative assembly processes. However, the decrease in process failures and in completion time observed could also be due to a learning effect among the trials, especially considering the simplicity of the product involved in the assembly process.

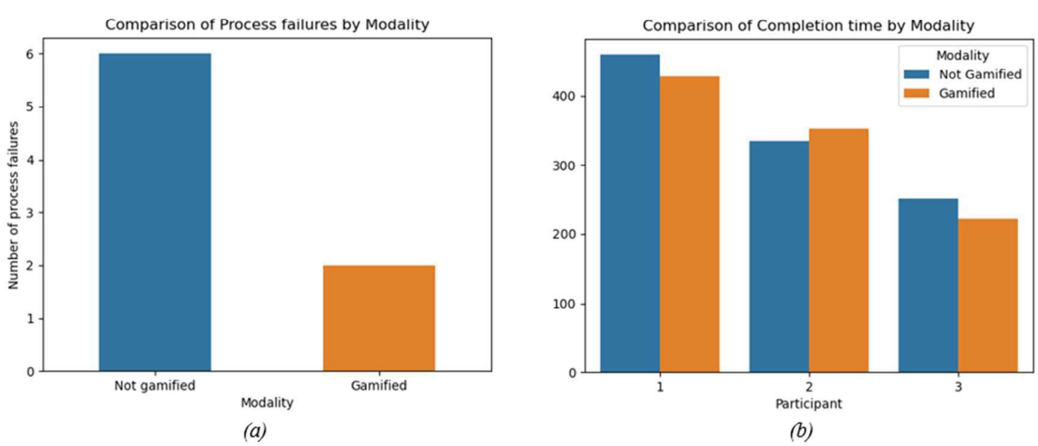


Figure 4 – Barplots showing sum of process failures by modality (a) and the average completion time for each participant distinguished by modality (b)

Impact of gamification on physiological signals

In the analysis of the impact of gamification on physiological signals, data on EDA and HRV were also collected. Fig. 5 shows the average value of the four metrics presented in section 5.1 by participant. For participant 1 and 2, both average SCR and SCL are higher in the non gamified modality compared to the gamified one. Participant 3 showed more similar results between the two modalities, with an increased average SCL level in gamified modality. However, metrics of heart rate variability generally led to opposite results. First, this could be due to individual differences in stress response, cognitive processing, and even familiarity with or preference for games could amplify these effects.

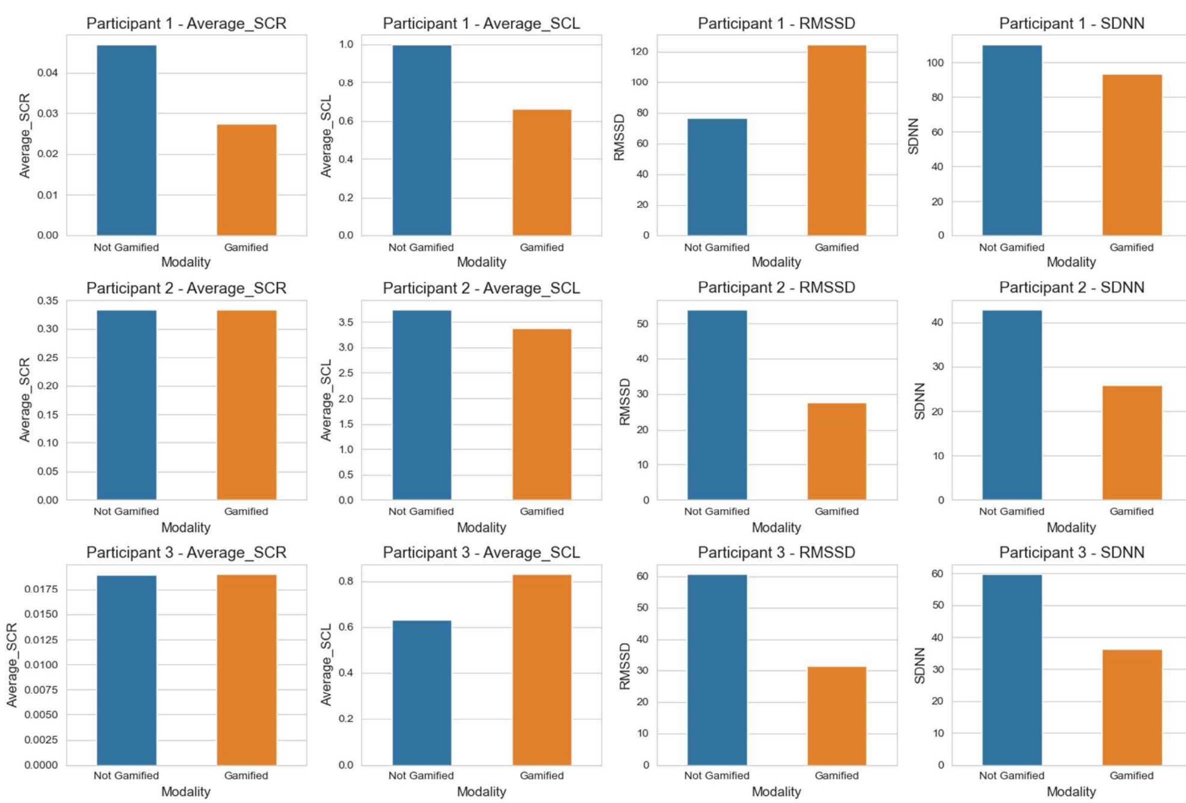


Figure 5 – Barplots showing the average trial value of the four physiological metrics for each participant distinguished by modality

Subjective responses

Subjective responses collected were: NASA-TLX, SAM and IMI questionnaires. The results of NASA-TLX questionnaires show that across all participants, perceived workload appeared lower in the gamified modality compared to the non gamified modality (see Fig. 6). Specifically, participant 1 showed the most significant difference in perceived workload between the two modalities, with a lower workload reported for the gamified approach. This may indicate a positive response to the gamification elements, suggesting that such modifications may have the potential to make the task more enjoyable or mentally manageable for this participant. For participant 2 and 3 the difference is less pronounced than for Participant 1, while also reporting a lower workload for the gamified modality.

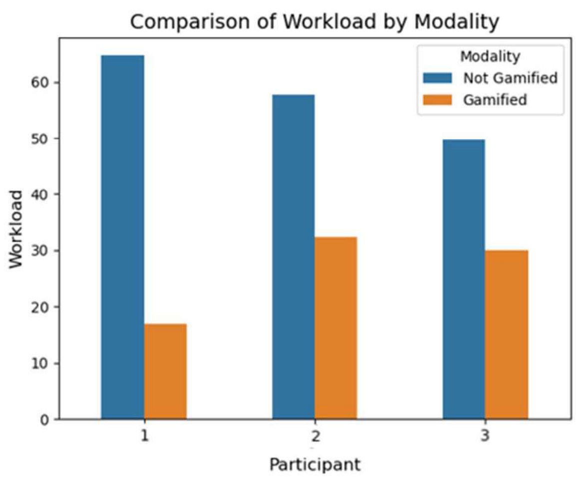


Figure 6 – Barplots showing the workload value of for each participant distinguished by modality

The bar graphs in Fig. 7 presents the results of the Self-Assessment Manikin (SAM). For all participants, valence is higher in the gamified modality compared to the other one, indicating a more positive emotional response when engaging with gamified elements. Participant 1 and Participant 2 show a decrease in arousal from non gamified to gamified, suggesting that the gamified elements may have reduced the intensity of their emotional response, possibly due to increased engagement. All participants reported higher dominance scores in the gamified modality, suggesting that they felt more in control when the task was gamified. This could be due to the gamification elements providing clearer goals, feedback or a sense of progress, which can increase the perception of control over the task.

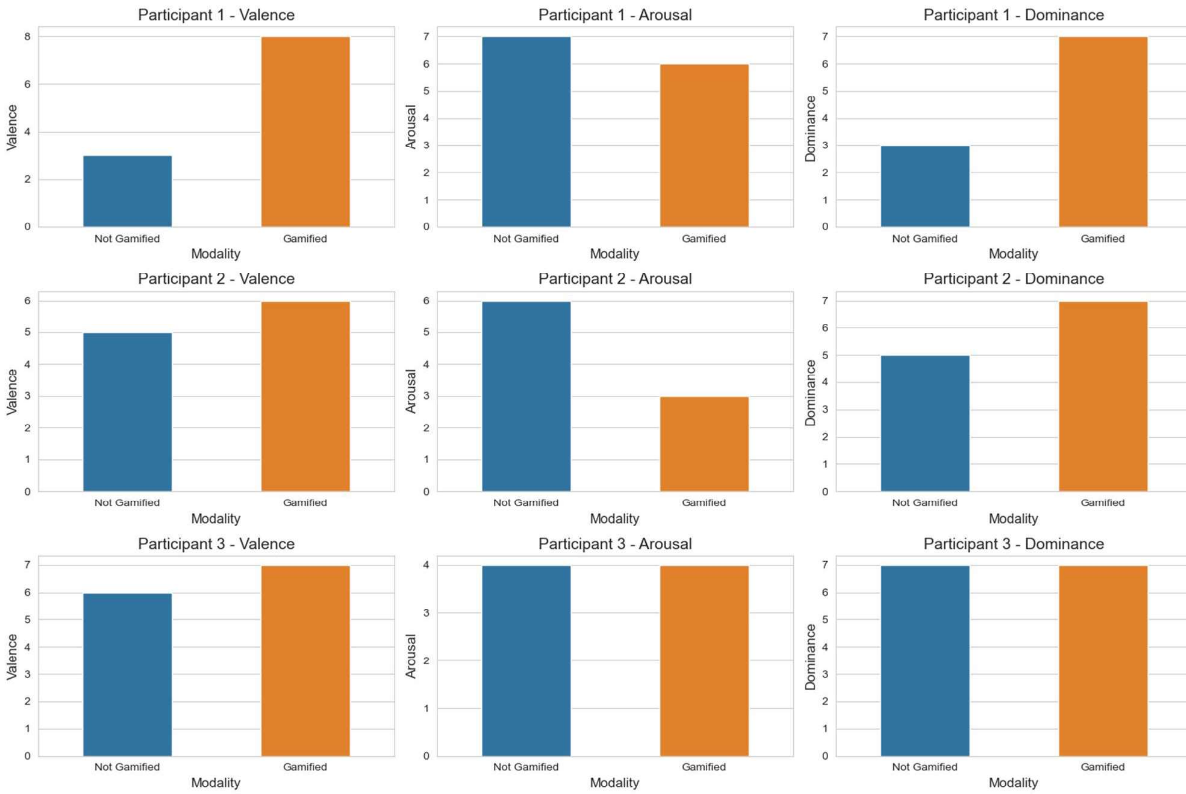


Figure 7 – Barplots showing the results of SAM for each participant and dimension distinguished by modality

Finally, the results of IMI are reported in Table 4. It can be noted that there's a trend towards higher scores for the gamified modality on items that directly assess enjoyment and interest ('I really enjoyed this activity', 'This activity was fun to do', 'I would describe this activity as very interesting', 'I found this activity quite enjoyable', 'While I was doing this activity, I thought about how much I enjoyed it'). For items related to tension and anxiety ("I felt very tense while doing this activity", "I was anxious while working on this task"), participants generally reported lower scores in the gamified modality. Furthermore, responses to items related to attention and boredom ('I thought this was a boring activity (R)', 'This activity did not hold my attention at all (R)') also favour the gamified modality, albeit with some variation across participants. Overall, subjective measures across several show a preference for the gamified version, suggesting that gamification can enhances the subjective experience of tasks.

Table 4 – Results of the Intrinsic Motivation Inventory (Ryan *et al.*, 1983) where values in bold indicate all that items where gamified version was preferred (“NG” refers to not gamified modality, while “G” for gamified one)

IMI - Interest/Enjoyment	**Participant 1**		**Participant 2**		**Participant 3**	
Items	**NG**	**G**	**NG**	**G**	**NG**	**G**
I enjoyed this activity very much	**2**	**6**	**4**	**6**	6	6
This activity was fun to do	**2**	**6**	**5**	**6**	5	5
I thought this was a boring activity (R)	**6**	**2**	2	2	2	2
This activity did not hold my attention at all (R)	**5**	**2**	3	3	**4**	**3**
I would describe this activity as very interesting	**2**	**6**	**4**	**5**	**3**	**4**
I thought this activity was quite enjoyable	**2**	**6**	**3**	**6**	5	5
While I was doing this activity, I was thinking about how much I enjoyed it	**1**	**5**	**3**	**4**	**2**	**4**
I felt very tense while doing this activity	**5**	**2**	**5**	**2**	**6**	**5**
I was anxious while working on this task	**5**	**2**	**5**	**2**	**5**	**4**
I felt pressured while doing these	**5**	**1**	**5**	**2**	5	5

Unstructured feedback

The unstructured feedback received from participants consistently highlighted the increased ease and engagement of the gamified version of the assembly process. A common suggestion was the need for a larger screen for the interface, suggesting that improved visibility could further enhance the user experience perhaps using projectors or augmented reality devices. In addition, participants expressed a desire for more personalised feedback within the gamification system. They suggested the inclusion of adaptive difficulty levels that would adjust the challenge based on the user's performance. Finally, participant 1 and 2 expressed interest in incorporating more storytelling elements into the gamification system. This feedback suggests that embedding the tasks within a story could increase the immersion and emotional involvement of the participants, making the work more meaningful.

CONCLUSION

This exploratory study addresses the potential of integrating gamification into collaborative assembly processes to assess its impact on operators' engagement, motivation and the overall quality of manufacturing output. Using the Octalysis framework, this paper introduces gamification elements to the manufacturing environment, with the aim of improving both operators' qualitative experiences and quantitative performance metrics. In this regard, performance metrics observed a trend towards efficiency in the gamified environment, although results varied between participants. Subjective ratings, instead, consistently showed a preference for the gamified modality, indicating increased job satisfaction and reduced stress. Finally, physiological data revealed complex and heterogeneous responses. Nonetheless, all participants showed a preference towards gamified version of the assembly process. The main limitation of the study is both the small sample size, which limits the generalisability of the findings, and the specificity of the case study to a single assembly process. This specificity may not fully capture the variety of scenarios encountered in different manufacturing environments. However, the aim was to explore the feasibility of gamification in manufacturing and provide a foundational perspective for future research. The next phase of research will expand the experiment to include a larger sample size for more robust statistical analysis, and test the gamification framework across different assembly processes to assess its broader applicability. In addition, the incorporation of narrative elements into gamification strategies is identified as a promising area to further enhance employee engagement.

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