Towards a Gamification of Industrial Production. A Comparative Study in Sheltered Work Environments

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ABSTRACT
Using video game elements to improve user experience and user engagement in non-game applications is called "gamification". This method of enriching human-computer interaction has been applied successfully in education, health and general business processes. However, it has not been established in industrial production so far.

After discussing the requirements specific for the production domain we present two workplaces augmented with gamification. Both implementations are based on a common framework for context-aware assistive systems but exemplify different approaches: the visualization of work performance is complex in System 1 and simple in System 2.

Based on two studies in sheltered work environments with impaired workers, we analyze and compare the systems' effects on work and on workers. We show that gamification leads to a speed-accuracy-tradeoff if no quality-related feedback is provided. Another finding is that there is a highly significant raise in acceptance if a straightforward visualization approach for gamification is used.

Author Keywords
Gamification; assistive technology; computer-assisted instruction; augmented reality; human machine interaction

ACM Classification Keywords
I.2.1 [**Applications and Expert Systems**]: Games; Industrial automation; K.3.1 [**Computer Uses in Education**]: Computer assisted instruction; H.5.1 [**Multimedia Information Systems**] Artificial, augmented, and virtual realities; Evaluation/methodology; K.4.2 [**Social Issues**]: Assistive technologies for persons with disabilities; H.5.2 [**User Interfaces**]: User-centered design; Evaluation/methodology; H.1.2 [**User/Machine Systems**]: Human factors, Software Psychology

EICS'15, June 23 - 26, 2015, Duisburg, Germany

ACM 978-1-4503-3646-8/15/06…$15.00
DOI: http://dx.doi.org/10.1145/2774225.2774834

Figure 1: Production workplace with gamification. The visualization of is projected to the right.

INTRODUCTION AND MOTIVATION
Gamification is a delightful concept: it is a creditable idea to use "videogame elements to improve user experience and user engagement in non-game services and applications" [6]. After all, increased engagement should have numerous benefits like improved performance and greater user satisfaction [23]. However, while gamification has a long tradition in health and education and is starting to be applied for general business processes (see section State of the Art) it is not yet established in industrial production.

It is surprising that gamification has not yet spread into industrial production: many processes there have physical outcomes (e.g. the number of parts produced at a specific machine per hour). These outcomes usually are measured and transferred to business intelligence systems like ERP (Enterprise Resource Planning) or PPS (Production Planning System).

Thus gaming elements like progress visualization, scores and leaderboards could be implemented with little effort and their use seems like a natural step. Even if "fun at work" might not be the core interest in industrial production environments, the number of errors and the number of accidents are without doubt. These numbers are undoubtedly influenced by the workers' engagement. So if gamification can be shown to increase engagement, its implementation in the industrial domain should become imperative.

Our contribution to the gamification of industrial production has four components:

1. We discuss why work in industrial production is suitable for gamification and which requirements are specific to this environment. We also examine the role of elderly and impaired production workers.
2. We describe a generic concept for the gamification of industrial production.
3. We present two systems which augment workplaces by gamification (Figure 1 shows the second one). Both systems are based on a framework for context-aware assistive systems but represent different approaches to gamification.
4. Finally we present a comparative study conducted in sheltered work organizations. The effects of augmented or "gamified" workplaces on work and on workers are analyzed and compared.

While the resulting findings are basic and correspond to intuition, they are meant to provide a secured data basis for future systems attempting a gamification of industrial production.

BACKGROUND

In this section we portray relevant background from outside computer science: current developments in industrial production work (1) and recent changes regarding the workforce (2). The section is aimed at persons with no or little background in the area of industrial production.

Work in Industrial Production

Repetitive work done by humans is generally prone to errors: so why is it not possible to automate all production? As a general rule, large lot sizes and simple tasks are indeed automated, as cost effectiveness is a paradigm in industrial production. However, installing and programing automated machines or robots as well as the necessary feeding systems is expensive – so for smaller lot sizes manual assembly often still is the more economical option.

One could assume that small lot sizes are the exception – but quite on the contrary: in recent years the growing demand for customized products has resulted in an increasing number of product variants [14]. More variants result in smaller lot sizes and thus an increasing need for manual production. These developments make systems which augment manual production work even more relevant.

Elderly and Impaired Persons in Production

As a result of the demographic change there is the trend that more elderly persons continue working; also there is a relative increase of older employees (especially in Europe and Japan). In concordance with the International Classification of Functioning, Disability and Health (ICF) by the World Health Organization (WHO) we talk about "elderly" when referring to persons aged 60 and above [32]. While these often excel in knowledge and experience, it has been shown that they tend to suffer from a gradual reduction of working memory and a decrease of learning abilities [28].

Under normal circumstances elderly persons do not think of themselves as being disabled because they consider certain deficits as "appropriate" for their age [11]. However, in industrial production environments already small deficits in concentration or short term memory result in an increase of human errors and production time in manual assembly tasks. As a consequence, many elderly workers feel unfit for their job and retire early. Companies and political economy would benefit if this loss of experienced workforce could be avoided by augmenting workplaces.

At the same time the work of persons with disabilities becomes more important; many countries oblige companies to employ a share of persons with disabilities. This obligation can be met by contracting "sheltered work" or "supported work" organizations. These organizations are also required to work economically [21], so most of them are eager to establish systems empowering their employees to meet the rising customer demands and become more profitable. Thus they are ideally suited for testing augmented workplaces.

STATE OF THE ART

The state of the art is diverse: On one hand there are numerous examples from the application of gamification in the education and health domains; also gamification is being applied in general business processes. On the other hand there currently is almost no work (apart from the authors' own) in the domain of industrial production.

Gamification in Education and Health

It was in educational contexts that some years ago the term "serious games" was established for learning software with multimedia elements and small games. This origin is natural, since "learning games" are probably as old as institutionalized learning: countless illustrated stories and mnemonic tricks show that pedagogy and games are strongly related. The serious games approach, i.e. the use of elements from game design to improve learning, is an example of "gamification" before that term was widely used.

The difference between regular and "serious" games is that the latter promote "serious" purposes, such as learning a foreign language or traffic signs. If we follow the philosopher Bernard Suits' sententious definition of gaming, that "playing a game is the voluntary attempt to overcome unnecessary obstacles" [31], serious games as well as gamified applications in other areas are no "real games" because they have a purpose outside of themselves – they have "necessary obstacles".

Like education, healthcare is an area where often only repeated exercises lead to success. So in both learning and training or rehabilitation, motivation and the ability to tolerate a certain amount of repetitiveness are key success factors. Thus the step from "serious games" to "games for health" again was a natural one.

One of the early examples was *Re-Mission* developed in 2007 – a shooter game where children with cancer could actively fight against virtual tumor cells. Playing the game led to a significantly higher reliability in the children's medicine intake [13].

In 2007 the approach reached a new level with the release of Nintendo's Wii which uses the accelerator-based Wii Remote and Balance Board. They allow to detect movements in three dimensions and made the user interact more directly with various health applications. Soon, scientists and physicians started to exploit the motion analysis capabilities for therapeutic use. The effects were promising: an analysis of efficacy between traditional and videogame based balance programs showed positive evidence for the latter [3]. A well-documented example is the game *VI-Bowling* which helped visually impaired users to increase their throwing skills [24]. An example targeting elderly users is *SilverPromenade* which simply allows players to go on virtual walks [9].

When the Kinect was launched in 2010 the technological cycle of adopting and adapting video game motion technology initiated by the Wii started again. Soon researchers and therapists wanted to make use of the markerless motion tracking capabilities to "gamify" medical and health treatment. One of the first Kinect-based games built for therapeutic purposes was *motivotion60+* which includes several gamified balance and strength exercises that help senior citizens to prevent falls [2].

Gamification in Business

After gamification was successfully applied in the domains education and health it spread to other areas. In recent years there have been attempts to "gamify" business processes. As mentioned above, the concept of applying gamification to general business processes has been described by Reeves & Read [26]. A more recent discussion of gamification as a "social technology" for companies is provided by Hugos [10].

This shows that the business approach "management by objectives" already implicitly has taken a step into the world of games. In gaming, missions and goals need to be stated explicitly to be transparent for players and measurable for the software. Thus, it is not surprising that gamification was well received in business contexts: in 2011, at the begin of the gamification hype, Gartner optimistically predicted that 70% of Global 2000 businesses will manage at least one "gamified" application by 2014 [33]. Such predictions become more reasonable, if gamification is understood as a means "to incentivize employees by establishing clear goals and rewarding those employees that achieve those goals" [33]. In such an understanding the gamification of business processes primarily is a visualization of management by objectives.

Assistance in Production

As discussed in the section 'Introduction and Motivation', the current state of the art of assistive systems in industrial production does not incorporate gamification elements. Nevertheless it is important to show how they look like and for which purpose they have been designed.

The purpose of most assistive systems in production is regulating production time and serving as a "quality gate". This means they are designed to support a steady production speed and identify and remove "waste" (i.e. failed products) from the workflow. Often these systems operate in a spatial and temporal distance from the workplace and the worker. Thus production workers usually lack the opportunity to learn from problems and errors on the fly.

Figure 2: A workplace-integrated assistive system using a monitor to display instructions for upcoming tasks. The workplace is typical for manual assembly tasks.

Most manufacturers are very conservative when changing human machine interaction (HMI) and prefer "safe and slow" over "new and intuitive". As a Fraunhofer HMI-study explains, from the variety of modern interaction techniques, so far only touch screens (an example is shown in Figure 2) found their way into production environments [1].

This conservative attitude is a result of their higher security and reliability requirements. New forms of HCI are more readily implemented in HMI environments if they have become part of an accepted standard such as ISO 9241 [12].

In spite of this careful attitude there are first efforts in the industry to reach a continuous analysis of work processes. This is a pre-requisite for real-time feedback and thus the potential gamification of production. An example is a system by Sarissa GmbH. As is customary in the manufacturing industry, the system's specifics are unpublished. It is based on ultrasonic waves. These are emitted by "trackers" attached to gloves the assembly worker has to wear and received by sensors mounted above the assembly table. The system compares the worker's motions with pre-stored motion sequences in real-time and provides feedback if the motions deviate.

This and similar advances show that the manufacturers of assistive systems for production are aware of the technical advances and try to incorporate them into existing assistive technology. However, social engineering methods such as gamification are not yet in their focus: if current assistive systems in production use visualization at all, they focus on describing the upcoming working steps on a display, usually as a combination of an image and a technical text (see Figure 2). The idea of using context-specific feedback to engage workers is yet an unexplored concept in this domain.

REQUIREMENTS

In this section we discuss in which respects work in industrial production is suitable for gamification and which requirements are specific for this environment.

In opposition to games or computer-based office work the user's default focus in manual production work is not a software interface but the product itself. This results in a potential dilemma: if assistive elements such as gamification become too prominent, they potentially distract the user from the main focus. Thus it is important to reduce distraction from the center of interaction and follow one of Shneiderman's Golden Rules by supporting the internal locus of control [29]. For gamification to be useful and accepted in industrial production contexts, it has to be discrete and "stay in the back". This results in the following requirements for an ideal implementation, which have partly been described in previous work [19] :

R1: implicit interaction

As described in the state of the art section, implicit interaction has already found its way into the industrial domain. However, systems based on gloves using ultra-waves have shortcomings: the glove itself is a distraction for the worker and can only track a single point in the glove's center. Taking into account recent research in computer science, an implementation of motion recognition without gloves and without trackers is preferable. Systems with depth cameras recognizing the pose [30] and even hand gestures [35] have been described. Such a system improves both the amount of information on the user's actions and the usability.

R2: in-situ projection

A good way to reduce distraction from the center of interaction is moving relevant information there: "in situ". While it would be disadvantageous to integrate a monitor into the work table's plate, the use of projection in office environments has been established 15 years ago [25]. More recently projection has also been applied to the industrial domain [8, 19, 27].

R3 (future work): detection of excitement level and type

For controlling and adapting gamification elements it would be beneficial to have a "backchannel". Knowing a user's emotional state would allow to discriminate behaviors which have similar consequences (e.g. faster production) but different causes (e.g. stress versus joy). This requirement could be met by detecting the user's heart rate, using galvanic skins sensors or by analyzing facial expressions. However, in the basic work presented here R3 has not been addressed – it remains a topic of future research and is discussed in that section.

GENERIC CONCEPT FOR GAMIFIED ASSITANCE

In the following we describe a generic concept for gamified assistance in production environments. It is based on a model from the area of assistive technology and a framework from the gaming domain.

Our concept for gamified assistance is based on the established Human Activity Assistive Technology Model (HAAT) which describes four basic components and functions [5]:

- activity (areas of performance, e.g. work, play)
- human ("intrinsic enabler", including skills)
- context (setting, social, cultural, physical)
- assistive technology ("extrinsic enabler") which integrates a human-technology interface, an activity output, a processor and an environmental interface

For gamified assistance the component 'assistive technology' has been adapted in three aspects:

1. the environmental interface output is realized by projection
2. the environmental interface input is realized and natural interaction (NI) using motion recognition
3. the activity output is enriched by gamification.

As described in the state of the art, motion recognition allows the user's body to become the controller. Thus there is no need for purposeful or even conscious interaction as the system's environmental interface directly interprets the user's actions. This is important to satisfy R1 and R2.

The second base of our concept for gamified assistance is a framework for an adaptive game system. Its central idea is a permanent observation/adaptation loop based on the user's actions (Figure 3: dotted area).

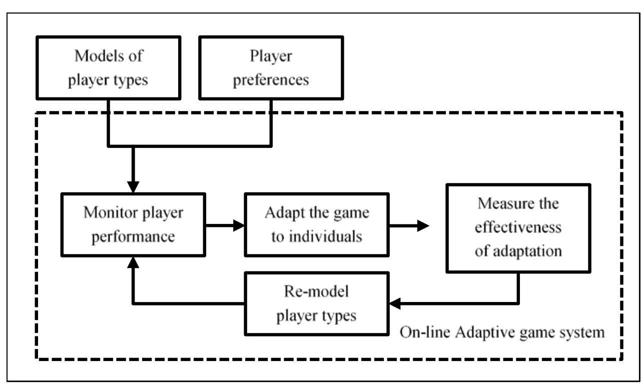

Figure 3: Framework for an adaptive game system.

This architecture aims "to provide a more appropriate level of challenge, smooth the learning curve, and enhance the gameplay experience for individual players regardless of gender, age and experience" [4]. The authors imply that such adaptations "decrease task-based failure and error rates among users" – an outcome which exactly matches the specific requirements in production environments (see section 'Background').

The interaction in this framework is realized explicitly, e.g. by mouse, joystick or gamepad. In contrast our concept for gamified assistance uses "natural" or implicit interaction based on motion tracking. However, there is no fundamental difference regarding the frequency of interaction: in both cases the users interact with the system almost permanently. As long as the gamification system receives feedback several times per second, the process of creating interventions can be almost instantaneous as well.

Another element of the adaptive game system is the player type. In game design, this relates to playing styles such as explorer, killer etc. In more restricted scenarios like production, the user can be characterized as an "achiever". Thus the main task of a gamification system for industrial production is measuring the work performance in real-time and creating appropriate interventions.

However, for creating adequate interventions a major challenge for gamified assistance is to interpret changes correctly: a decrease in performance can be both, the result of boredom or the result of resignation due to overextension. As described in the requirements section (here: R3) an ideal system would also detect the emotions.

IMPLEMENTATIONS

In this section we present two implementations of gamified systems for production workplaces. Both are based on the generic concept presented in the previous section, but the realization of interventions and the visualization differ strongly. While System 1 has also been described in previous work [16, 17, 20], System 2 was designed on the basis of the experiences with System 1 and has not been described before. Table 1 lists their main differences:

Table 1. Comparison of two gamified workplaces.

Feature	Implementation 1	Implementation 2
Visual Output	monitor	projection
Physical Design	assembly table built for the experiments	integration in the regular workplace
Complexity of Visualization	high: 8 elements 'Production Tetris'	low: 3 elements 'Circle & Bars'
Assembled Product	car undercarriage built by Lego bricks	metal shears (actual product)

Physical Integration in the Work Environment

The first augmented workplace (Figure 4) is a simplified version of a regular assembly table as used in the industry. The design was aimed to provide an experimental setup for the first advances in gamification with natural interaction. Additional design aims were reducing distractions, easy transportability and the ability to adjust the work surface in height to allow access for wheelchair-bound persons.

Like its industrial counterparts the table has been constructed to meet the requirements of the authoritative VDI 2860 on Technology for Assembly and Handling [34]. It was built from aluminum profiles and weighs about 70 kilograms. The base to the left supports a monitor. The top cage holds a motion detection system (Kinect). It is mounted 1.4 meters above the table's plate to minimize distraction and provide sufficient coverage of the working area.

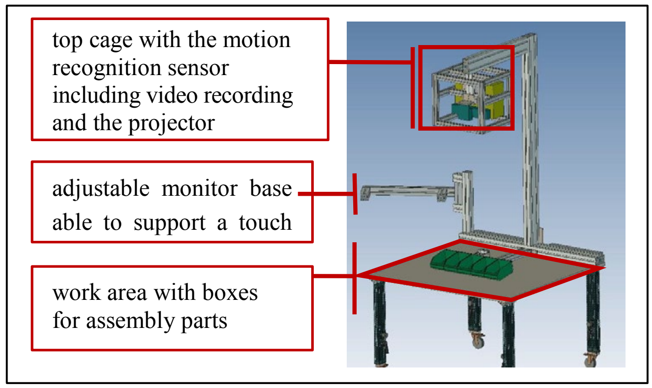

Figure 4: Physical implementation of the gamified workplace using sensors and projection.

Although some potentials of projection were explored with this experimental system [19], we did not use projection to visualize the gamification, as Figure 5 (left) shows.

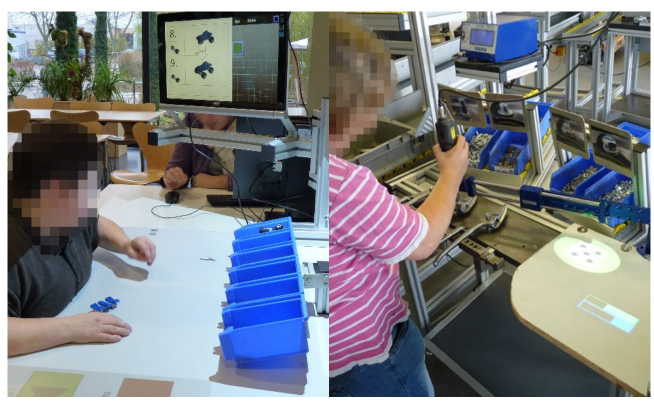

Figure 5: System 1 (left, Production Tetris) uses a monitor to display gamification elements while System 2 (right, Circles & Bars) projects them into the workspace.

However, we used projection in System 2 (Figure 5, right). As shown in Table 1, the overall aim was to simplify the system while integrating it into the user's regular work environment. So instead of designing a second rendition of the experimental table, we used a projector to bring the visualization directly to the working area.

Software Architecture

The software architecture underlying both implementations is based on two modules:

- Module A analyzes movements in the work area, records and stores the user data.
- Module B interprets the motion data to generate the interventions for gamification.

Module B is the focus of this work; the implementation of motion recognition in Module A has been described in previous work [20] and is summarized in the following paragraph.

Due to the required top mount of the sensor, Module A could not use the skeletal joints extracted by the middleware (OpenNI or the Microsoft SDK). Instead it exploits the depth images generated by the motion sensor. It recognizes movement patterns by analyzing the changes of z-values in pre-defined 3D areas. The module also logs each passage through a 3D area. The passage receives a timestamp and (if applicable) a flag stating if it was correct or false with respect to the assembly instructions. This enables the system to detect if a user picked a wrong component or misplaced a part. However, due to the limited resolution of the motion sensor a more advanced analysis was not possible: at the time of the studies, securely determining if the product was assembled without errors still required an additional analysis of either the recorded video or the finished product.

Implementation of Gamification

While both systems use visual feedback to visualize the performance and motivate the workers, the implementation of gamification (Module B) differs strongly. In System 1 each work process is represented by a brick in a puzzle game resembling Pajitnov's classic Tetris (Figure 6), so the concept was called "Production Tetris" [16].

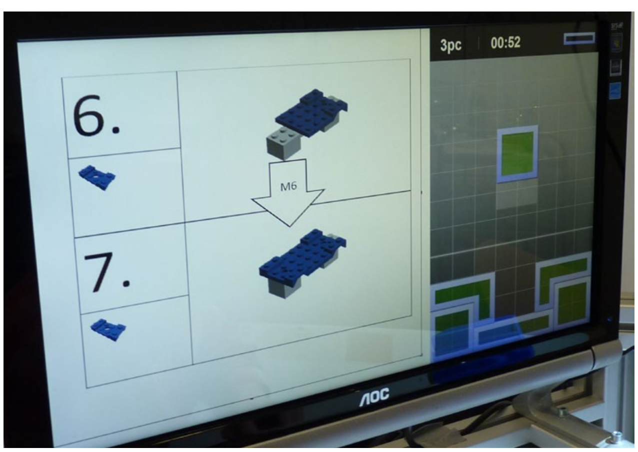

Figure 6. The gamification visualization is displayed right of the instruction.

While the worker performs an assembly process the brick moves down with its color changing from green to red. The duration of this change is derived from the individual user's previous assembly sequences.

Additionally the mean process speed of the last three assembly sequences is represented by a "shadow brick". Thus a worker can always check how the current work is turning out compared to the recent personal average. As a typical assembly sequence involves several processes (eight in the study with the 'Production Tetris' visualization) the visual result of each production sequence is a tower of several colored bricks. After a sequence is completed, the build-up tower disintegrates.

To understand the changes in the second implementation we briefly summarize findings from the evaluation of System 1. With the Tetris-approach we wanted to create an intuitive visualization. However, the evaluation showed that numerous colored bricks were in fact perceived as complex. So although the users liked that "something" was built, they did not intuitively understand that the coloring of individual bricks matched their respective performance.

As a result an important aim when designing System 2 was to simplify the visualization even more. Instead of combination of colored bricks, the resulting "circle and bar" approach (Figure 6) just uses a single circle to represent the current work process. It includes a die showing the corresponding process number. Similar to the Tetris bricks the circle's color changes from green to red. Additionally its radius permanently decreases.

The speed of these changes is based on the user's previous assembly sequences. Next to the circle there are two bars. After each completed work step, a fixed ratio of the remaining circle area is added to the green sequence bar, gradually filling it.

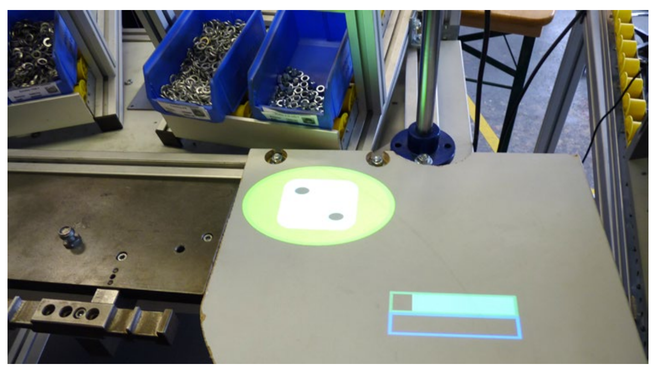

Figure 7. Gamification elements projected next to the work area. The circle represents the current process, the bars show the current and the overall performance.

After a sequence is completed, the filling of the sequence bar is moved to the blue overall bar. Thus the user can observe the performance in the current work step, in the current sequence and in general with just three elements (Figure 7).

STUDIES

The studies were conducted to observe and analyze how work and workers in production are affected if their workplaces are augmented by gamification.

Settings

Both studies were conducted at sheltered work organizations. Serving as sub-contractors of production companies they provide authentic state of the art production environments. However, for these organizations the implementation and evaluation of new work-related augmentations is a regular process, which was a decisive advantage for conducting the studies. Another advantage of this environment is the fact that work with impaired persons currently is becoming increasingly important in "regular" industrial production (see background section).

Both sheltered work organizations were located in Germany. The study of System 1 was conducted at the Beschützende Werkstätte Heilbronn (BWH), an organization providing work for about 1.000 workers with impairments. System 2 was evaluated at the Gemeinnützige Werkstätten und Wohnstätten Sindelfingen (GWW) which provides over 1.300 workplaces for impaired persons.

Test Populations and Setup

The workers in the study had mild cognitive and partly also mild motoric impairments. To make sure that they still were able to perform the required tasks we talked to their supervisors to get an individual assessment of their skills. We also checked the skills were in a pre-study where a 10-piece Lego car had to be assembled.

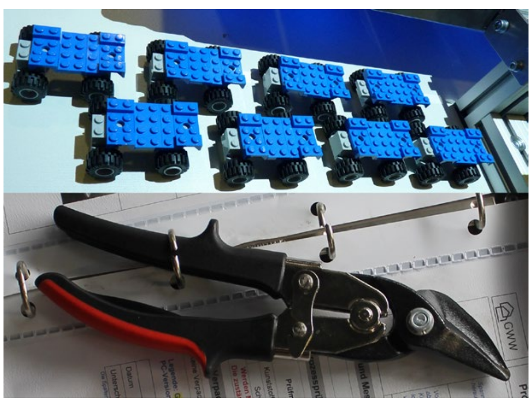

Figure 7. Products assembled in the studies: Lego cars (top, 9 work steps) and metal shears (bottom, 5 steps).

For System 1 the test population of 40 users was divided into two sub-groups with 20 users each. The first group worked with a state of the art assistive system: it only displayed the assembly instructions on a monitor. The second group used a system augmented by gamification. The visualization was displayed on the same monitor directly next to the regular assembly instructions (Figure 5 left, Figure 6). As described in the implementation section (Table 1) the design of the pioneering System 1 was aimed at conducting experiments – and so was the task: the subjects had to assemble identical Lego cars, each of which required 9 work steps (Figure 7, top).

For System 2 with a test population of 10 users, we took a different design approach: the aim was to come as close to the regular work environment as possible. We chose a real product the workers' were familiar with, so no visual instructions were required.

The task was to assemble metal shears in 5 work steps each (Figure 7, bottom).We used a repeated measures approach with 10 assemblies with gamification and 10 assemblies without gamification.

Results

In both setups we measured production time and error rates; all values are given in minutes (m) and include standard deviations (SD). We also used a questionnaire to analyze the user experience. With regard to production time, the hypothesis was that gamification increases engagement and thus reduces production time.

As expected, the mean time per production sequence (i.e. the assembly of one product) is reduced by both systems when augmented by gamification (Table 2, Figure 8).

Table 2. Comparison of mean production times.

Implementation	SotA	Gamification
System 1 "Tetris"	$\bar{x}$ = 3.20 m SD = 1.13 m	$\bar{x}$ = 2.80 m SD = 0.86 m
System 2 "Circle & Bars"	$\bar{x}$ = 2.03 m SD = 0.75 m	$\bar{x}$ = 1.90 m SD = 0.61 m

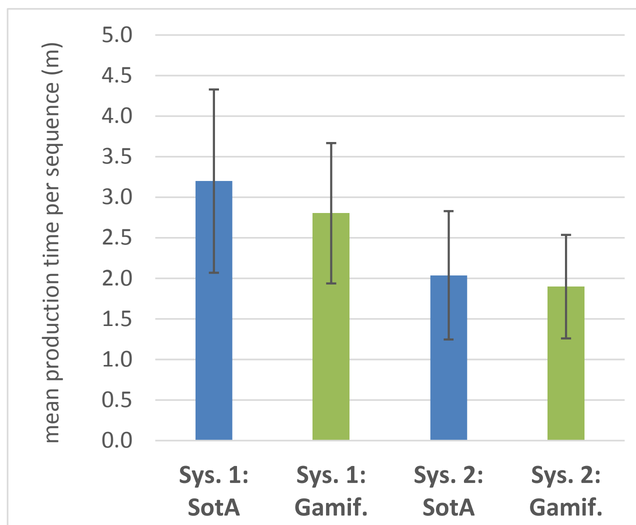

Figure 8. Production times with gamification (green) and without gamification (blue) in both systems.

System 1 'Tetris' reduces production time by 12.5% while System 2 'Circle & Bars' results in a 6.4% reduction. Also both systems reduce standard deviations: System 1 by 23.9% and System 2 by 18.7%.

However, the high variance which makes it difficult to secure these results statistically, even if an alpha error of 0.10 is considered as acceptable. For System 1, the hypothesis that gamification reduces production times has to be rejected ($p>0.11$). Still the data led us to believe that there is potential for time reduction. With the adjusted gamification approach of System 2 the hypothesis that gamification reduces production times receives weak statistical support (p<0.09, marginally significant).

When we look at the number of errors our expectation was that gamification leads to a quality drop, as a result of a speed-accuracy-tradeoff. As described in the implementation section, current technical restrictions prevented the implementation of real-time error detection in the systems. Like in the analysis of production times, both implementations produce matching results: as expected the number of errors is increased when the work is augmented by gamification (Table 3, Figure 9).

Table 3: Comparison of mean error rates.

Implementation	SotA	Gamification
System 1 "Tetris"	$\bar{x}$ = 22.6% SD = 17.5%	$\bar{x}$ = 33.1% SD = 22.1%
System 2 "Circle & Bars"	$\bar{x}$ = 9.0% SD = 23.9%	$\bar{x}$ = 15.0% SD = 20.1%

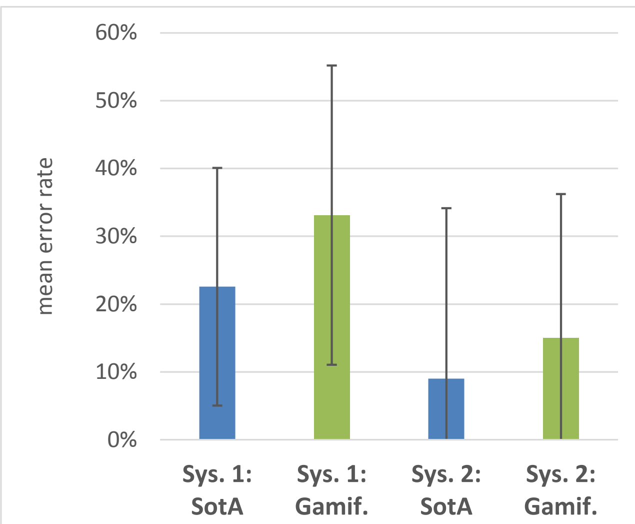

Figure 9. Effect of gamification (green) on production error rates in comparison to the state of the art (blue) in both systems.

With System 1 the number of errors is consistently higher than with System 2. This probably is a consequence of the artificial Lego product in the experimental setup. Here the error rate's absolute increase of 10.5% results in a relative increase of 46.5%. In System 2, where the familiar product resulted in a lower overall error level, the absolute increase in errors of 6.0% results in a relative increase of 66.7%.

For System 1 the hypothesis that gamification increases the error rates can be supported (p<0.06). With the gamification approach of System 2 this hypothesis cannot be confirmed statistically (p>0.28) in spite of the increased error rate.

The high variance in error rates indicates that larger groups with 50 or more tests subject will be required to secure these basic findings of error rates. Also the findings regarding the reduction of production speed, a potential positive outcome of gamification, needs additional statistical confirmation. Generally the trend towards higher error rates when gamification is integrated – especially in error-intolerant production environments – results in a new requirement:

R4: gamification in production environments requires real-time error detection methods

Results: Acceptance

For the evaluation of the systems' users experience we used an identical questionnaire based on the system usability scale [22]. Before the experiment started, we evaluated the attitude towards it as well as the physical and mental state. This is especially important with impaired persons where strong changes can occur within a few hours. Although some subjects expressed unease or uncertainty at the beginning, this pre-evaluation showed that in both studies all participants were motivated and in a good mood. We also used rephrased questions to counter-balance problems with comprehension or affirmative tendencies.

As discussed in the implementation section, our goal with System 2 'Circle and Bars' was to reduce the complexity in comparison to System 1 'Tetris'. This strategy was a direct result of the low acceptance of the gamification approach in System 1 (Figure 10), where the mean acceptance on a scale from 1 to 5 was only 1.9 (SD = 0.4) while the corresponding rejection rate was 4.2 (SD = 0.5).

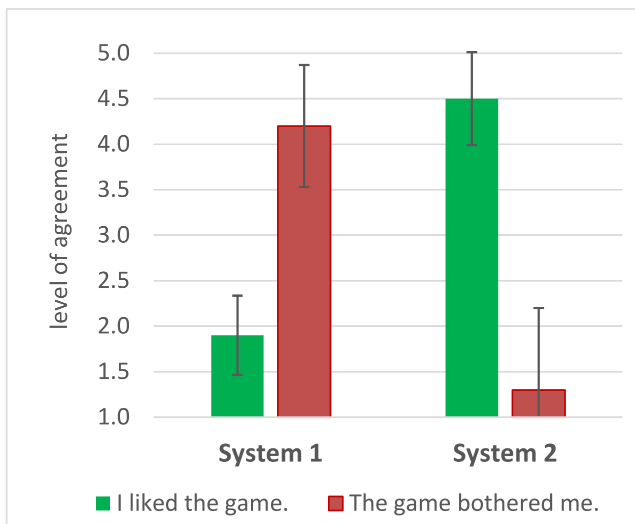

Figure 10. Acceptance of gamification (green, col. 1, 3) versus rejection (red, col. 2, 4) in both systems.

Also the qualitative findings from interviews with users of System 1 'Tetris' showed that the high complexity of the visualization was confusing for them. While they liked the bricks building up, the color-coding was often misunderstood or ignored. As a result we expected that the simplified visualization of production progress in the Circle and Bars approach will increase acceptance.

Indeed the acceptance of the visualization of gamification changed clearly: with the simplified System 2 the mean approval rate was 4.2 (SD = 0.7) and the corresponding rejection rate 1.3 (SD = 0.9). The hypothesis that the simplified visualization increased the acceptance of gamification was strongly supported both for both the positive phrasing ($p<0.0000001$) and the negative phrasing ($p<0.000001$).

Also the interviews showed that the users appreciated System 2 which was described as "motivating" or "a fun change". So a qualitative finding is that straightforward gamification elements clearly increase short-term engagement in production work. However, the long-term sustainability of this effect remains a question for future research.

CONCLUSION

Research on the potentials of gamified assistance in the domain of industrial production is just starting. Nevertheless the two implementations presented here clearly show that motion recognition allows implicit interaction with gamified assistive systems in production environments.

The studies illustrate how gamification in production environments currently is a double-edged sword: while increasing the production speed, the errors rates also go up. This finding corresponds to the common observation in HCI that a reinforcement in one area often results in a compensation in another area – in this case a speed-accuracy-tradeoff. However, the current studies focus on impaired users. The tradeoff might be less obvious if gamification is applied with un-impaired users. Also users without cognitive impairments might tolerate slightly more elaborate visualizations. Such a general investigation of the potential of gamification in industrial production remains subject to future work.

However, independent of the users' skill level, the tradeoff is a result of the fact that both pioneering systems could not detect errors in real-time, so the interventions created were not quality-specific. Thus the findings result in the derivation of an important new requirement: *gamification in production environments requires real-time error detection methods.*

Another finding is related to the user experience of gamification. In opposition to most "real games" the systems' graphical appeal does not correlate with acceptance [18]. When comparing the visualization approaches, there is a highly significant raise in acceptance when a very straightforward approach is used for gamification.

FUTURE WORK

On the technical side, the accuracy of the motion recognition has to be improved. This can be achieved by combining several depth sensors (e.g. Kinect and Leap Motion) with object detection. First steps in this direction have already been taken [7]. This improvement would allow real-time quality assurance. The second step would be answering the question: does gamification with quality-related feedback still increase production speed and engagement? Since errors are an exception to the regular workflow, i.e. they happen scarcely, we see a good chance that the increased speed and engagement are maintained in overall.

The subsequent step would be a long-term study to check if these positive effects prevail or perish in everyday work life. The fourth and final step is evaluating, if the results gained in studies with workers with impairments can be generalized for un-impaired workers.

Another huge improvement would be the implementation of emotion detection (R3). However, a comprehensive monitoring of the user's emotional state gives rise to ethical questions and might be rejected by employees and their representatives. These issues need to be addressed – a first concept to "black box" an emotion detection system in order to prevent misuse has already been described [15].

ACKNOWLEDGMENTS

Our thanks go to the BWH (Beschützende Werkstätte Heilbronn) and the GWW (Gemeinnützige Werkstätten und Wohnstätten Sindelfingen) for supporting the studies.

This work was part of the project motionEAP, supported by the German Federal Ministry of Economics, grant no. 01MT12021E.

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