How to Train Employees, Identify Task-Relevant Human Factors, and Improve Software Systems with Business Simulation Games

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Abstract

In today's globalized world, cost pressure, the demand for higher production efficiency, and growing product diversity lead to increasing complexity of manufacturing and business processes. Insufficiently understood human and social factors further increase this complexity. Game-based learning environments and business simulation games can reduce this complexity by identifying and understanding the contributing human factor. Business simulation games can be used (1) to identify and quantify human as well as social factors influencing the effectivity and efficiency, (2) to assess the aptitude of prospective employees and identify suitable training interventions, (3) to improve management and production software, and (4) to present effective, efficient, and entertaining training environments. By allowing employees to investigate cause-and-effect relationships of simulated manufacturing and business environments, they can test and understand the consequences of their actions in safe environments. In this paper, we report a practical case of a business simulation game for conveying quality management strategies. The development of the game is presented along the definition of learning objectives, the underlying System Dynamics model, and the design of the user interface. The evaluation of the game reveals that human factors relate to the simulation's metrics. Finally, we give guidelines to design and develop game-based simulation and training environments.

Keywords

Game-Based Learning, Simulation-Based Learning, Serious Games, Vocational Training, Human Factors, Usability, Usability in Production Engineering

1 INTRODUCTION

Today's manufacturing companies are facing profound changes due to increasing globalization, supply chains growing in size and complexity, and innovations in industrial Internet. An increasing number of product variants, growing demands on product quality, and shorter lead times pose tremendous challenges for employees managing the flow of information and materials across supply chains of companies. Companies that successfully manage the increasing complexity, reduce the variance of production processes, and enable employees to successfully handle variance will gain the necessary competitive advantages to sustain at tomorrow's markets.

Diverse technical approaches target the increase of overall productivity and to make systems more resilient against variances [1]. Still, the human factors' perspective is often neglected despite its evident importance: Studies show that overall productivity can be increased if ergonomics and human factors are adequately considered [2,3].

Preparing employees to handle complexity, variance, and uncertainty is also delicate. Often, courses and learning modules in schools, universities, job training, or advanced trainings focus on teaching single bits of information. However, parts of the complexity of today's world stem from its interconnectedness and reciprocal interference. We argue that this interconnectedness is difficult to communicate and that adequate simulation models embedded in game environments allow employees to gain a deeper and connected understanding of the complexity of today's world. This networked thinking will empower employees to handle the increasing complexity successfully [4].

The structure of this article is as follows: Section 2 defines the terms *game-based learning* and *serious games* and gives examples from business and production engineering. Section 3 contours the benefits of game-based learning environments. Section 4 demonstrates the development of a game, the underlying simulation model, and the development of the benchmark function that was used to investigate our hypotheses. Next, Section 5 depicts studies that investigated and (mostly) confirmed the hypotheses of the versatility of these games. The article concludes with Section 6 and a summary and discussion of game-based learning environments to strengthen the competitiveness of companies.

2 BACKGROUND AND EXAMPLES

A literature review on the terms "*serious games*" and "*game-based learning*" yielded over 2 million results each. Even for the domain of production engineering, the examples for game-based learning are ubiquitous. Therefore, we start with a formal definition of serious games and implications for production engineering (Section 2.1), alongside the most prominent examples of serious games for production engineering (Section 2.2). A comprehensive overview of business simulation games is given in [5].

2.1 Background

Serious games are typically used to mediate knowledge or behavior change for educational purposes. They are entertaining but not intended primarily for amusement [6]. Furthermore, Michael and Chen state that game models are simplified abstractions of a problem and not necessarily complete and precise [7]. Prensky even argues that serious games will be the most successful method for the Millennials' and following generations' education as they grew up fully surrounded by technology and often find conventional media and earlier didactical approaches boring and cumbersome [8].

As shown above, the necessary skills to manage the complexity of today's world is beyond declarative knowledge; rather it includes procedural knowledge and the understanding and internalization of cause-and-effect relationships. Bogost highlights that the procedural rhetoric of serious games persuades to increased interaction with a topic which yields a deeper understanding of the modeled processes [9].

2.2 Examples

First, Forrester's Beer Distribution Game (BDG) illustrates the effect of variance along a supply chain by placing several players along a supply chain for an alcoholic beverage [10]. Ordering information is passed upstream (from a retailer to a factory), whilst goods are delivered downstream, each with a short time delay. The game serves two learning objectives: First, the players are sensitized to the "bullwhip effect", i.e., orders along supply chains are prone to escalation. Second, sharing information reduces this escalation.

Goldratt's game is a second prominent example and demonstrates the difficulties that arise from variances in delivery reliability or product quality [11]. The game is similar to the BDG, however, depending on random factors, only a subset of an order is delivered. This introduces significant variance along the supply chain and makes meeting the market's demands difficult.

Both games are typical contents in business, engineering, and management classes, because they raise the awareness for critical aspects of supply chain management. Players need to find a trade-off between different components of the system and have to understand that optimizing for a single aspect of the environment is insufficient and detrimental. Hence, successful players develop an understanding of the interconnected system (and its interdependent factors), infer the current state of the system from a limited number of variables, and choose the optimal or an adequate of many possible actions. The proficiency of players can then be evaluated by investigating the players' actions or their overall performance.

3 THE VERSATILE BENEFITS OF GAME-BASED LEARNING ENVIRONMENTS FOR MANUFACTURING AND BUSINESS

This section postulates that game-based learning environments in manufacturing and business offer several short- and long-term benefits for academia and industry. The following arguments militate in favor of this posit.

First, by studying workers' behaviors and their decisions, the game environments can **measure individual workers' skills and their awareness** for effective and efficient handling of specific situations in production environments. Hence, they are suitable recruitment tests and can identify training demands, if workers lack the respective skills or awareness.

Second, the game environment can serve as **training environment** in order to sensitize future employees for the challenges of production processes and to gain experience in handling specific situations that occur during these processes. Difficult situations can be explored and trained without putting the company at risk.

Third, that game-based learning environments are a versatile method to understand the underlying human factors. They can **identify cognitive, social, or emotional aptitudes** that are beneficial or crucial for handling complex situations.

Forth, we argue that game-based learning environments can help **advance business software**, as they can be used to empirically study how information presentation, amount, and complexity influence the decision quality of employees. Also, they can be a benchmark with high ecological validity to evaluate changes and new features in enterprise software.

The overall utility of the game environment in this context can be demonstrated by investigating the relationship between user factors (e.g., age, expertise, cognitive abilities), interface factors (e.g., font sizes, screen layouts, visibility of key performance indicators), and the complexity of the simulated environment (e.g., seasonal movements vs. predictable linear growth) on metrics from within simulated environment.

4 DEVELOPING GAME-BASED LEARNING ENVIRONMENTS

The development of a game-based learning environment builds on three fundamental constituents: First, a simulation model that provides a suitable abstraction of the world, and in our case, an abstraction of a supply chain, a company, or a production process. Second, a user interface that communicates the state or part of the state of the simulation model to the user and allows the user to interact purposefully with the simulation model. Third, one or multiple functions from within the simulation model that serve as a benchmark to evaluate the performance of the players.

This paper illustrates the development steps using a game-based learning environment for mediating expertise in material disposition and quality management for manufacturing companies. Although this example and the simulation model are quite specific, the general development procedure can easily be adapted to other learning objectives or application contexts.

4.1 Development of a simulation model

This section exemplifies the development of an abstract simulation model for a game-based learning environment. It is based on the Quality Intelligence Game (QIG); a detailed presentation of this model, its motivation, and the underlying assumptions are presented in [12]. The development of a model is based on three interleaved steps. Frist, the learning or research objectives need to be defined. Second, a model of the necessary cause-and-effect relationships needs to be specified. Third, based on the identified relationships, simulation functions are specified for each component.

As a first step, the learning objectives need to be identified. For this game, two objectives were selected that have to be balanced by the players: As in the BDG (see above), the first goal is to maintain sufficient stocks of a product and to always fulfill the orders of a simulated customer. The second goal incorporates product quality into the BDG and high product quality ought to be achieved by investing in the incoming goods inspection and in the internal quality assurance. The objectives are to increase the awareness for the importance of quality management and to increase the skill of the players to apply quality management strategies.

The second step is the identification and definition of the components and cause-and-effects relationships between the components in the models. We suggest using a System Dynamics model [10] as a basis for this work. In our example, the model consists of the components for 3-tiers of a supply chain with the external supplier (S), the player as the manufacturing company (M), and the customer (C). Other components that relate to the production process are also part of the model. For example, in our model the supplier's and internal production qualities can change over time. Further components are the number of intact and broken parts delivered from the supplier (both depend on the supplier's production quality), the number of intact or broken parts in stock (depending on the deliveries), the number of goods complained about by the customer (depending on the stock and the internal production quality), and the net profit achieved (depending on complaints by the customer, investments for quality inspections, stock keeping, and stock-out-penalties). Figure 1 shows an overview of this model.

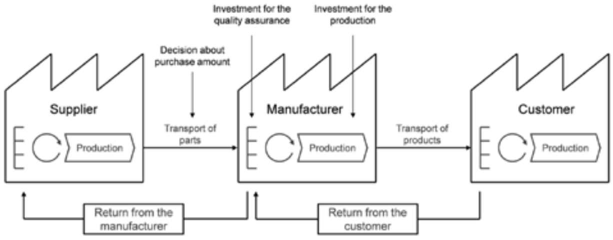

Figure 1 - Simplified model of the Quality Intelligence Game (QIG)

For reasons of simplicity and controllability, the current model is designed for a single player that controls the material disposition and quality management of the manufacturing company (M) whereas supplier (S) and customer (C) are simulated through an artificial intelligence.

This step is the most difficult and most crucial part of developing a game-based learning and simulation environment: On one side, the model needs to be sufficiently complex to capture all previously defined learning and research objectives. On the other side, it should not be too complex, as the following implementation steps will be more difficult and the users will have more difficulties to interact and understand the model [13].

In the third step, the simulation of the model's components is defined as functions of the previously identified cause-and-effect relationships. For example, the stock level S at a given time t is based on the previous stock level, the goods ordered from the supplier O, and the deliveries D to the customer:

$$S(t) = S(t-1) + O(t-1) – D(t)$$

The net profit P(t) at a given time t is based on the current stock level S(t) and the per part stock-keeping costs $cost_{Stock}$, the investments in the incoming goods inspection I_{igi} and the internal production quality I_{ipq}, the costs for the complained parts, and the revenue R(t) for the delivered parts:

$$P(t) = R(t) – c_{Stock} \times S(t) – I_{igi}(t) – I_{ipq}(t) – C(t-1)$$

A deeper presentation of the model is given in [12]. Depending on the modeled process or company and the addressed learning and research objectives, the parameterization of the functions can weight specific factors (e.g., out-of-stock penalties) as more important than others by assigning different penalties and rewards to them. We argue that the parameterization should relate to the objectives and the later use context of the game.

After the full specification of the simulation model, it can be implemented and tested as a low-fidelity prototype (e.g., in a spreadsheet application) or as functional application in a programming language.

4.2 Development of a user interface

In order to let players interact with the simulation, a user interface needs to be designed and implemented. Again, this step depends on the learning objective defined at the beginning.

First, developers need to identify which of the variables from the simulation model should be visible to the user and which should be concealed. The latter is important, as often parts of the model are intentionally hidden from the user. For example, the internal production quality in QIG is designedly invisible to the user, as she or he has to infer changes to this metric from other variables. Obviously, not all variables need to be visible all the time and the user may be given the option to request additional information on specific variables (e.g., the temporal trend of a variable or a decomposition of aggregated values). Second, the designers must also reflect how to represent each variable as an indicator in the user interface. For example, variables can be represented numerically ("102 parts"), using analog scales, as absolute or relative values ("production up 10%"), or using traffic lights ("stock level red").

For this design process, it is advised that developers consider relevant guidelines during the design and development of the user interface [14,15] and consider the learning and research objectives. For example, the user interface development for the QIG started as paper prototype: By this, the necessary indicators and controls for interacting with the model could easily be redesigned and evaluated until a suitable spatial layout was found.

Third, the simulation model and the user interface must be implemented as computer applications. Although some simpler games can be played as board games (e.g., Beer Distribution Game), we argue for using computer applications, as they can easily handle sophisticated simulation models, can log each simulation step, and log every user interaction for later analysis. For the QIG, the game was realized as a web application using Java EE and the PrimeFaces framework. Following the Model View Controller pattern (MVC) [16], the user interface (V) is distinctly separated from the simulation model (M) and one component can be changed without affecting the other.

4.3 Choosing meaningful benchmarks

Even an abstraction of a company offers various metrics to investigate. As the main objective of a manufacturing company (or likewise of a division or cross-company supply chains) is the realization of profits, the net profit P(t) seems to be the most suitable generic metric. It includes costs for investments, stock keeping, out-of-stock penalties, and penalties for complaints due to low product quality. Obviously, the inspection of other variables from the simulation may also provide valuable insights, depending on the learning objective or specific research question. For example, lead times, achieved customer satisfaction, or total product quality may also be worth studying. These metrics are already part of the simulation model (s. Section 4.1) and their relationship with the users (abilities), the user interface (visual and cognitive ergonomics), or simulation factors (complexity of the environment) can be investigated.

5 EXAMPLE: THE CASE OF A QUALITY MANAGEMENT GAME

This section outlines the empirical studies carried out to show game-based learning in the four previously mentioned application fields. Although the findings relate to the presented QIG and an implementation of the Beer Distribution Game we did earlier, the general methodology is transferable to other game and simulation environments.

5.1 Training environment

Our studies show that the games are suitable training environments as interacting with them had a significant influence on three key variables [17,18]: First, in both games, the users showed an increase in net company profits between multiple rounds of the game. Hence, players learned to perform their tasks and understood how to react to the challenges in the game. Second, in the quality management game, the average product quality also increased. Hence, the central learning objective was achieved. Third, summative questionnaires revealed that players had a higher awareness for the mediated learning objectives, i.e., the awareness for the bullwhip effect and quality management increased.

5.2 Identification of training potentials

In line with the previous section, the investigated metrics (achieved net profit, product quality, and awareness) can likewise be used as benchmarks to identify the suitability of a potential employee for a specific task or to identify training potentials.

Similar to an assessment center or as a part of one, candidates might be screened for their domain skills using an adequately designed simulation. Selection criteria might be how fast candidates get acquainted with the system (i.e., learning curve) or the performance achieved on average. However, the reliability and external validity of this approach is currently unexplored and further studies need to investigate the predictive power of achieved game performance on later job performance. Likewise, this approach may also identify training potentials. If the performance achieved is below a certain threshold or erroneous reactions are performed in specific situations, the system might suggest adequate training interventions.

5.3 Identification of human factors on performance

Regarding the identification of underlying human factors relating with performance in the business simulation games the results are promising, though they leave room for further research endeavors [17–

19]. No strong relationship between game performance and a set of investigated personality factors (different between the studies) was discovered yet. Still, some findings were coherent across all studies: The players' performances in later rounds of the game were strongly correlated with the performances from earlier rounds. Consequentially, some players are better in the game and others are not, which is a strong indicator for the existence of yet undetected personality factors that will eventually explain performance.

5.4 Evaluation of user interfaces

Multiple experiments investigated and quantified the influence of information presentation and usability on the players' performance.

An experiment in the context of the game revealed that usability and decision complexity interact in regard to performance, meaning that employees have additional and often avoidable difficulties to make correct decisions in complex situations if the data presentation is inadequate [20].

In a second study, a holistic refinement of the game's user interface was compared with the original interface [18]. The revised interface featured a process-oriented layout of screen elements and controls and integrated several key-performance indicators on important variables of the game (e.g., stock-level, product quality, refusals). To investigate the influence of this refinement, a randomized trial with both interfaces as between-subject variable and all other aspects, such as the game's complexity, held constant was carried out. The results show that reorganizing the interface towards a process-oriented presentation and the integration of key-performance indicators support players to achieve higher overall profits and higher product quality.

Future studies will break down the several changes to the interface and individually quantify the efficacy of data presentation, interface layout, and the presence of key-performance indicators. The long-term objective is to develop visualizations of relevant company metrics that adapt to the current user and context to support employees in difficult situations. This approach offers the opportunity to test and evolve user interfaces and user interface guidelines for engineering enterprise software under more realistic conditions than in controlled laboratory studies.

6 DISCUSSION

Embedding simulation models of supply chains, companies, or production processes in games enables players to interact with several aspects of the respective system simultaneously. They can develop, test, and evaluate hypotheses about the relationships of the environment, and deduce a holistic understanding of complex and heavily interconnected systems. Hence, these environments can and should be used to prepare employees for their job and to enable them for networked thinking necessary to sustain in today's world. Using games is especially useful for motivation and to address Millenials and later generations. These generations grew up with current entertainment technologies and are reluctant to use conventional media and prior didactical approaches in their education. We showed that using game-based learning environments increased the awareness for the selected learning objectives and increased the skill of the players to handle the required tasks.

Companies further profit from this approach as they can easily and cost-effectively identify training potentials for their employees or identify personnel with high suitability for the task. At the same time, the game-based simulation and learning environments can then be used as a fun, entertaining, and cost-efficient training intervention.

We demonstrated that these games could also be used to evaluate changes to the user interfaces or work environments. Software development companies of Enterprise Resource Planning Systems can therefore use game-based simulation environments to identify key interface aspects contributing to increased effectivity, efficiency, and user satisfaction [21]. Interface developments can be benchmarked along the models' relevant cost functions and our studies found evidence for the positive influence of interface refinements and the integration of key performance indicators on profit.

Although we identified a strong correlation between a player's performances across the levels, none of our thus far tested factors related well with the overall game performance. The conclusion of this is two-fold: First, the correlation hints at the existence of one ore more general human traits that explain performance. Second, this or these factors still remain unidentified and require further investigation.

Concluding, game-based learning and simulation environments for manufacturing and business are a viable method to increase the competitiveness of manufacturing companies.

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8 REFERENCES

[1] Schuh, G., Stich, V., Brosze, T., Fuchs, S., Pulz, C., Quick, J., et al., 2011, High resolution supply chain management: optimized processes based on self-optimizing control loops and real time data., Production Engineering. 5, 433–442.

[2] Karwowski W., 2006, The Discipline of Ergonomics and Human Factors, in: G. Salvendy (Ed.), Handbook of Human Factors and Ergonomics, 3rd ed., John Wiley & Sons, Inc., pp. 3–31. doi:10.1002/0470048204.ch1.

[3] Calero Valdez, A., Brauner, P., Ziefle, M., 2016, Preparing production systems for the Internet of Things – The potential of socio-technical approaches in dealing with complexity, in: COMA'16 Conference, p. (in press).

[4] Anderson, L.W., Krathwoh, D.R., 2001, A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives, Longman, Inc., New York, NY, USA, doi:10.1207/s15430421tip4104_2.

[5] Faria, A.J., Hutchinson, D., Wellington, W.J., Gold, S., 2008, Developments in Business Gaming - A Review of the Past 40 Years, Simulation & Gaming, 40, 2008 464–487. doi:10.1177/1046878108327585.

[6] Abt, C.C., 1987, Serious Games, Madison Books.

[7] Michael, D., Chen, S., 2006, Serious Games: Games That Educate, Train and Inform, Thomson Course Technology.

[8] Prensky, M., 2001, Digital Natives, Digital Immigrants Part 1, On the Horizon, 9, 1–6. doi:10.1108/10748120110424816.

[9] Bogost, I., 2007, Persuasive Games: The Expressive Power of Videogames, The MIT Press, Cambridge, Massachusetts, USA.

[10] Forrester, J.W., 1961, Industrial dynamics, MIT Press, Cambridge.

[11] Goldratt, E. M., Cox, J., 1992, The Goal: A Process of Ongoing Improvement, 2nd ed., North River Press, Great Barrington, Massachusetts.

[12] Stiller, S., Falk, B., Philipsen, R., Brauner, P., Schmitt, R., Ziefle, M., 2014, A Game-based Approach to Understand Human Factors in Supply Chains and Quality Management, Procedia CIRP. 20, 67–73. doi:10.1016/j.procir.2014.05.033.

[13] Chandler, P., Sweller, J., 1991, Cognitive Load Theory and the Format of Instruction, Cognition and Instruction. 8, 293–332.

[14] Gould, J.D., Lewis, C., 1985, Designing for Usability: Key Principles and what Designers Think, Communications of the ACM. 28, 300–311. doi:10.1145/3166.3170.

[15] Calero Valdez, A., Brauner, P., Schaar, A.K., Holzinger, A., Ziefle, M., 2015, Reducing Complexity with simplicity - Usability Methods for Industry 4.0, 19thTriennial Congress of the International Ergonomics Association (IEA 2015).

[16] Gamma, E., Helm, R., Johnson, R., Vlissides, J., 1995, Design Patterns, Addison-Wesley Professional.

[17] Brauner, P., Runge, S., Groten, M., Schuh, G., Ziefle, M., 2013, Human Factors in Supply Chain Management – Decision making in complex logistic scenarios, Proceedings of the 15th HCI International 2013, Part III, LNCS 8018, Springer-Verlag Berlin Heidelberg, Las Vegas, Nevada, USA, pp. 423–432.

[18] Philipsen, R., Brauner, P., Stiller, S., Ziefle, M., Schmitt R., 2014, Understanding and Supporting Decision Makers in Quality Management of Production Networks, in: Advances in the Ergonomics in Manufacturing. Managing the Enterprise of the Future 2014 : Proceedings of the 5th International Conference on Applied Human Factors and Ergonomics, AHFE 2014, CRC Press, Boca Raton, pp. 94–105.

[19] Philipsen, R., Brauner, P., Stiller, S., Ziefle, M., Schmitt, R., 2014, The role of Human Factors in Production Networks and Quality Management. – How can modern ERP system support decision makers?, First International Conference, HCIB 2014, Held as Part of HCI International 2014, Heraklion, Crete, Greece, June 22-27, 2014. Proceedings, LNCS 8527, Springer Berlin Heidelberg, pp. 80–91.

[20] Mittelstädt, V., Brauner, P., Blum, M., Ziefle, M., 2015, On the visual design of ERP systems – The role of information complexity, presentation and human factors, 6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015) and the Affiliated Conferences, AHFE 2015, pp. 270–277.

[21] DIN/EN/ISO 9241–11, 1998, Ergonomic requirements for office work with visual display terminals (VDTs): Guidance on usability specifications and measures.

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