European Lean Educator Conference 2017

Measuring Lean competencies – An approach for quantifying the learning outcome of a simulation game

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1. Problems in evaluating the competence transfer of lean simulation games

Simulation games are widely applied in academic courses and programs for teaching the methods and principles of Lean Production (Bicheno 2015). Serious gaming situations in seminar rooms as well as learning factories are used for the development of the participants' competencies in Lean (Micheu, Kleindienst 2014; Michalicki 2016). The main thought behind the simulation game movement is the target to teach activity-oriented knowledge and competencies instead of simply theoretical knowledge (Tisch et al. 2014). In this regard, competency is defined as being capable of creatively solving problems with technical as well as instrumental knowledge and skills (North, Reinhardt 2005).

The research in cognitive-psychology confirms the theory, that despite the availability of theoretical knowledge, people fail to solve complex practical issues (Getsch, Siemon 2015). This problem even strengthens in linked process chains, like production and logistics systems, where small changes can create big effects over the whole system. Simulation games allow the participants to recognize and in particular to feel and experience the effects of management decisions on the whole process chain within a short time frame (Lang, Jung 2001).

Experts assume, that simulation games create a significantly higher long-term learning success through active experiences in the gaming situation. It is supposed, that through learning by doing and action up to 80 % of the knowledge remains long-term. This is a significant improvement over traditional learning transfer methods like reading (seeing) or lectures (listening) (see figure 1 (Schenk, Wojanowski 2004; Beckmann 2004)).

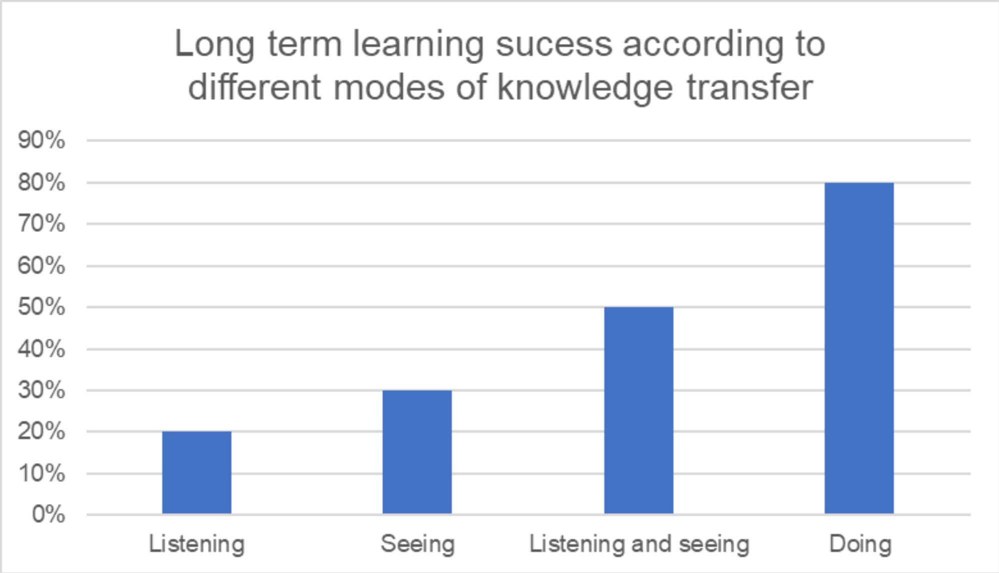

Figure 1: Long-term learning success (own representation based on (Schenk, Wojanowski 2004; Beckmann 2004)

Despite the increasing usage of simulation games, there are only a few empirical analysis about the effectiveness of different simulation game methods (Kriz 2009).

Measuring the competency development in Lean simulation games is mostly limited to simple feedback sessions at the end of the game. This seems not sufficient for determining the effectiveness and quantifying the target achievement of a simulation game (Getsch, Siemon 2015).

Therefore, the core research question of the paper is: “Does the participation in a Lean simulation game increase statistically significant the Lean competency of the participants?”.

The following two chapters provide some basics about simulation games as well as the measurement of the learning outcome. Section 4 describes the developed method for evaluating the effectiveness of simulation games and is followed by some insights and results of the first applications of the method at the Landshut University of Applied Sciences, Germany.

2. Simulation games

Simulation games, although getting more popular in education and training in the last few years, are not an invention of our times. Starting in India in 400 AD as an early version of chess, simulation games have their roots in the military sector (Kriz 2014). For training purposes of military officers simulation games were used already in the 18th century to achieve an improved knowledge an competency transfer (Kriz 2009).

During the early 20th century simulation games have been used not only for the transfer of knowledge, but to send a political or socio-critical message. A famous example is “The Landlord Game”, which is the early version of “Monopoly” (Kriz 2014).

Nowadays simulation games are used for different purposes. The focus is still on training within academia and industry. Current estimates refer on over 2000 different simulation game variants in all sectors (Kriz 2009).

For teaching the philosophy, the principles and methods of Lean, simulation games play traditionally an important role. Although you cannot learn about Lean without real practicing on the companys' shop floor ("Gemba"), "games allow the next best thing by fostering a richness of understanding, discussion, participation, and decision making that are essential elements for successful Lean implementation" (Bicheno 2015).

3. Basics of measuring the effectiveness of simulation games

The evaluation of courses in universities as well as further training and consulting in industry is a common practice. The feedback and assessment loops are the basis for the continuous improvement activities towards a more effective and efficient education.

Most evaluation concepts still relate on subjective assessments of the learning outcome by simple feedback forms. Objective ways for measuring the effectiveness of education are mostly missing.

A difficulty for the development of an evaluation concept for simulation games is caused by different definitions for central terms in this field of research. The literature differs roughly in **knowledge**, **skills** and **competency**.

For our research knowledge is defined as "the stock of facts, theories and rules, that are available for a person or a group" (Wimmer 2014).

Skills are defined as a kind of declarative knowledge, which is enriched with practice. Therefore, skills allow to solve concrete problems or tasks in a particular environment. Skills allow the execution of an activity, but do not allow to decide whether an action is successful in the individual situation (Wimmer 2014).

The term competency covers more than knowledge and skills. Characteristics like creativity or personal experience extend knowledge and skills to competency. Competency means in the context of this paper the ability to self-organized problem solving with reference to the individual skills and knowledge of a person or a group. The connection between knowledge, skills and competency can be seen in figure 2:

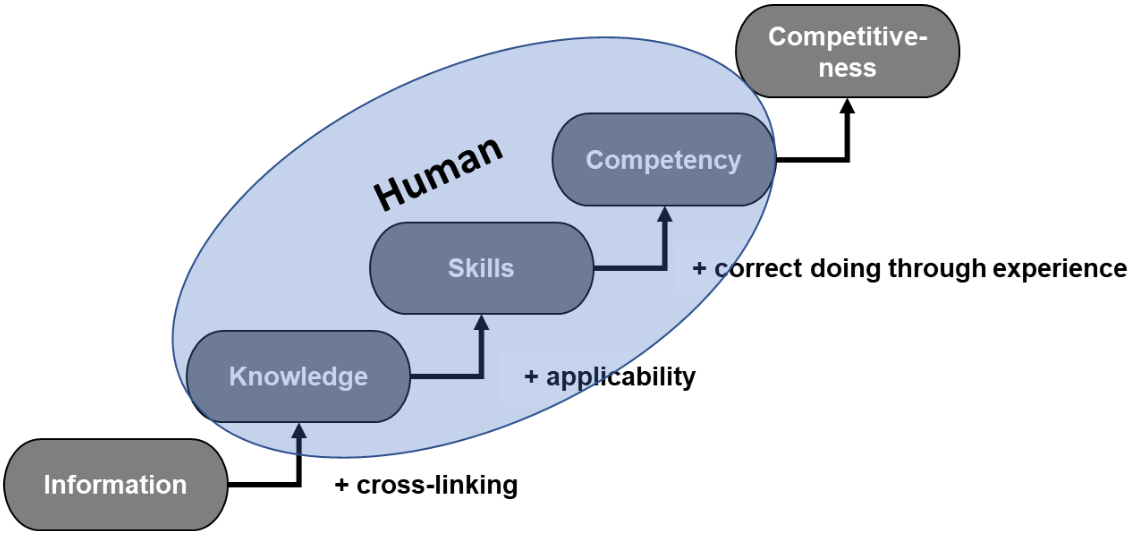

Figure 2: Categorisation of central terms (own representation based on (North, Reinhardt 2005)).

Competency consist of different factors, whereby a direct measurement of the competencies extent is hardly possible. A possible solution for this is to measure the single involved elements of competency, the growth of knowledge and the observation of the performance of a skill. This approach allows therby an indirect measurement of competencies. For the development of the evaluation concept it is necessary to link concrete competencies with appropriate skills and knowledge elements in a so called competency transfer table (Tisch et al. 2014). Table 1 shows the structure and a formalised example of a competency transfer table:

Table 1: Example of a competency transfer table (own representation according to (Tisch et al. 2014)).

Competencies		Skills		Knowledge					
1	Competence	1.1	Skill	1.1.1	Knowledge	1.1.2	Knowledge	1.1.3	Knowledge
		1.2	Skill	1.2.1	Knowledge	1.2.2	Knowledge	1.2.3	Knowledge
2	Design of a customer oriented and holistic production system, based on the principles of Lean Production	2.1	Performing a value-stream analysis	2.1.1	Calculation and usage of lead time	2.1.2	Structure and elements of a value-stream map	2.1.3	Interpretation of value-stream map
		2.2	Creating an operator-balance-chart	2.2.1	Calculation and usage of customer takt-time	2.2.2	Determination of cycle-times	2.2.3	Interpretation of operator-balance-chart
		2.3	Levelling the production system	2.3.1	Bottleneck (Drum-Buffer-Rope)	2.3.2	Identification of bottlenecks	2.3.3	Knowledge about Hajunka method
		2.4	Implementation of a suitable steering method	2.4.1	Pros and cons of push and pull concepts	2.4.2	Different kinds of pull concepts	2.4.3	Knowledge about the pacemaker process

For an ideal measurement of competencies TISCH recommends the following three steps (Tisch et al. 2014):

1. Identification of competencies and respective activities

2. Creation of a scenario, where it is possible to carry out the activities repeatedly

3. Communication of the starting scenario and the scenario targets to the participants.

During the simulation game, the activities of the participants can be observed according to a guideline, which allows a conclusion about the growth of skills and competencies. In addition to the structured observation with a guideline, specific interviews of some participants as well as knowledge questions to all participants support the evaluation of the game.

For the design of an appropriate evaluation concept, it is necessary to clearly specify the type of simulation game and its competency transfer goals. Therefore, the next section describes the measurement object, the Lean simulation game "From Push to Pull".

4. Description of the Lean simulation game "From Push to Pull"

The overall goal of the simulation game "From Push to Pull" is to introduce the participants to the basics of Lean Production and Lean Logistics. The game consists of four game rounds, in which toy tractors are produced in different ways (see figure 4). Each game round focuses on different principles of Lean.

Figure 3: Structure and Layout of the simulation game "From Push to Pull"

The starting scenario is the assembly line of a tractor production, with two tractor variants (red and yellow tractor). The goal for the entire system is to produce fifteen tractors in a ten-minute game period in sequence of the customer orders. Figure 3 shows the structure and layout of the simulation game.

At first the participants choose between the following different game roles:

- 4 assembly workers in the main line
- 2 assembly workers in the secondary line (engine hood assembly)
- 1 quality inspector
- 1 logistics worker for the material handling and
- auxiliary workers for time measurements and continuous improvement activities.

This simulation game can be described as a “closed” simulation game, which means that there is a mostly given structure. The participants are mostly guided by the game instructor. The general didactical goals are that participants firstly understand (“learning to see”) and secondly solve the given problems and tasks. More precisely, the following three competencies are taught:

- design of a waste-free internal and external logistics system with the use of Lean Logistics methods
- design of a waste-free workplace with focus on high quality and maximum productivity
- design of a customer oriented and holistic production system, based on the principles of Lean Production.

In summary, this simulation games teaches the way from a push to a pull oriented production system, including the necessary methods.

5. Concept of measuring the learning outcome of a lean simulation game

An evaluation concept was developed for measuring the transfer of competency in the simulation game. On the foundation of the competency transfer table, it was possible to assign concrete actions (skills) for observation as well as elements of knowledge for testing. See table 1 for an example of the competency transfer table. The whole evaluation approach consists of four elements (see figure 4):

1. Multiple-choice-tests of knowledge before and after the simulation game, where changes in defined elements of **knowledge** are analysed:
   The pre- and post-test consists of multiple-choice questions. Questions in these tests were about e.g. the definitions of lead-time, customer takt time, Kanban rules, 5S etc. The two tests allow a differential measurement of the knowledge growth.
2. Multiple-choice-tests for evaluating the participants’ impressions in the different production systems (push and pull oriented systems) used in the simulation game:
   In these two tests, the participants’ **skill** to recognize several types of waste is measured. This was done by asking them different questions e.g. “Do pull systems create over production?”.
3. Observations of the participants’ **actions** as an indicator of the technical and instrumental **skills** of the participants:
   As stated earlier, skills cannot be measured directly. Therefore, in the open fourth game round participants have to use their knowledge and skills to improve the production system. This open set-up allows the game instructor to observe the participants’ problem-solving skills e.g. in terms of using poka-yoke, two-handed assembly work or holistic value stream thinking.

4. Interviews and case study based discussions after the simulation game for measuring **knowledge** and **skills**:

   For an objective measurement of a single participants knowledge and skills, it is necessary to perform face-to-face interviews. The interviews where done four to eight weeks after the simulation game for measuring the long-term effectiveness. A written guideline supports the interviewing process. In the first phase of the interview, the participants do a self-evaluation of the learned competencies. After that, they solve a case study and a logistics planning task e.g. about the implementation of Kanban or JIT/JIS. This partly subjective and partly objective interview design allows the comparison of the self-evaluation with the measured data.

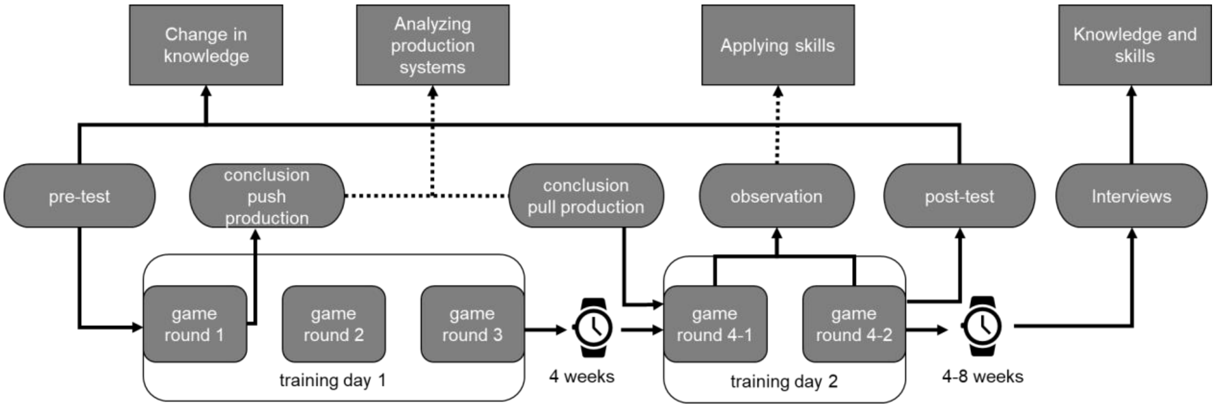

Figure 4: Concept for the evaluation of the Lean simulation game

By analysing the changes in knowledge as well as the observed skills, the devoloped evaluation concept allows to draw a conclusion on the development of the defined competencies (see section 4).

6. Application and results of the evaluation concept for the lean simulation game "From Push to Pull"

This evaluation took place during the lecture "logistics and factory planning" in the seventh semester of the course of study "Industrial Engineering and Management" at the Landshut University of Applied Sciences. The simulation game is a mandatory addition to the regular lecture and is held in groups of about 15 students.

The entire population consists of N = 113 students (17 % female, 83 % male). About two thirds of the population had prior knowledge in Lean Production through a different course of study "production and process planning" during the sixth semester.

Pre- and post-test

The pre- and post-test were conducted with an electronical voting/response system. The software of this system is a MS Power Point Add-Inn, which allows to create different types of questions (yes/no, multiple-choice with one or more answer options). After preparing the question slides, they were presented to the participants of the simulation game at defined times (see figure 4). The hardware of this systems consists of 30 remote controls, which were handed out to the students. During the tests, the students had to press the answer button which they thought represented the right answer on the slide.

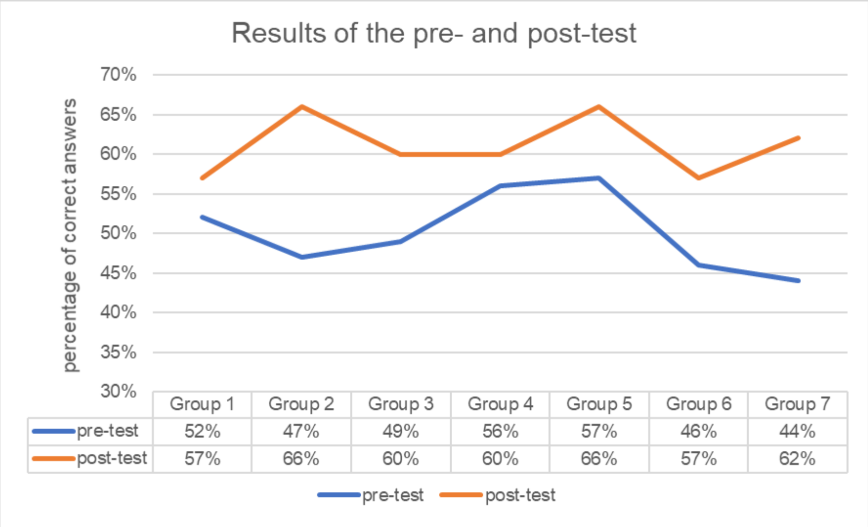

Figure 5: Results of pre- and post-test

Figure 5 shows the results of the pre- and post-test of the seven groups of students. In all groups, it was possible to measure a growth in knowledge. In average, 50 % of the questions in the pre-test were answered correctly. After participating in the simulation game, in average 61 % of the questions were answered correctly. This means a relative increase in knowledge of 22 %.

The system also offers the possibility to analyse the change in knowledge for every single knowledge element defined in the competency transfer table. The results of the post-test and the differential measurement offer a real-time feedback to the instructor. This can be used in two ways. On the one hand, the instructor can react immediately to point out some effects of the simulation game in detail and discuss them again. On the other hand, this can be used for further continuous improvement of the simulation game itself.

Conclusion to push and pull oriented systems

These multiply choice tests analysed, if the participants could correctly recognize the characteristics of the two different production systems ("learning to see waste"). Additionally, it is investigated, if the different game roles (see section 4) do have any effect on the learning outcome.

A regression analysis showed, that there is no statistically significant correlation between the percentage of correct answers and the weighted gaming role category (grade of immersion from 1 – time measurement role up to 5 – assembly worker in the main line). This interesting effect does not mean, that the practical experience of problems during the game is needless. On the contrary, the other findings show, that simulation games can convey competencies. It is rather an indicator for the fact, that experiencing a situation in a group is enough to create individual personal learning experiences.

Interviews

A random sample of n = 8 students were interviewed about their problem-solving skills in complex situations using an interview guideline and a case study.

The students were able to solve complex and new problem situations with the conveyed knowledge and skills even four to eight weeks after participating in the simulation game. This indicates a long-term growth in the defined competencies through the simulation game.

In general, the self-evaluation of the participants seemed to be to positive in comparison to the measured objective test results and observed skills. This creates a need for more objective measurement instruments for the evaluation of the learning outcome in simulation games. It also supports the hypothesis, that simple feedback sessions are inappropriate for the assessment of the simulation game effectiveness.

An interesting result of the interviews is, that seven of eight students do not think, that a more realistic gaming environment (like a learning factory) would support a better learning outcome. Therefore, simulation games in seminar rooms seem to be an adequate method for developing competencies of students.

7. Conclusion

This article developed a concept for the evaluation of simulation games in Lean education. The main challenge was the measurement of the growth in competencies. A competency is a highly individual and inherent characteristic of a person that consists of knowledge and skills (see figure 2). To handle this challenge, a competency transfer table was developed (see table 1).

As a conclusion, it can be stated that the measurement of growth in the different knowledge elements could be determined quite easily. The electronical voting/response system proved to be an excellent tool for quick an easy knowledge tests during the simulation game. Concerning the observation of the participants' actions, the observation process was hardly successful for analysing the extent of skills. One major reason for this is the fact, that this particular simulation game was not designed based on a prior competency transfer table. Therefore, the interviews subsequent to the simulation game proofed to be very valuable. The interviews allowed to observe, if students could apply the learned knowledge and skills from the simulation game in a new and different situation.

Therefore, the final recommendation is, that a simulation game and the respective evaluation concept should be developed in parallel. So it is recommended to start with the development of a competency transfer table and use this as a basis for structuring the simulation game. It is assumed, that the time-consuming interview process can be cancelled, if all observable actions can be detected already during the simulation game by the game instructor.

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