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Game-based Lean Production training of university students and industrial employees

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Abstract

Production simulation games are increasingly popular for training students and industrial employees in Lean Production principles. They range from paper- or desktop-based games to full scale simulators and proper manufacturing machinery. This paper reports on experiences from using both desktop games and a full scale simulator. Desktop games are suitable when training people who already have a fair understanding of lean principles. Shop floor workers usually have difficulties in seeing analogies between desktop games and their work environment. For both students and industrial workers, training effects and immersion tend to be higher when using full scale simulators.

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Keywords: Lean Production; Lean Games; Experiential Learning, Simulation, Industrial Training, Training Within Industry

1. Introduction

Within the Lean Educators community, much attention is being paid to Training Within Industry (TWI) and to training for professional preparation of engineering students using simulated factory environments. However, this concept is not new. Over a century ago, Herbert Schofield (then V-C at Loughborough University, UK) created what he called an “instructional factory” within the university [1]. This environment resembled a real factory with actual

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manufacturing machinery and was used to train industrial operators and engineering students alike, an approach that differed radically from the canned engineering education that was the prevailing teaching model at the time.

The findings reported in this paper are partly the result of literature searches (without pretending to present a full-scale literature review) using OneSearch (which covers many databases such as Scopus and SwePub) with search terms such as "lean production", "experiential Learning", "game based learning", "lean games", and "simulation based learning". Even general searches have been carried out as there is much material available published by lean education consultants. Although this latter material can be promotional in nature, it often contains references to scientific publications that can be of interest. Furthermore, experiences from training over 250 industrial workers and even more university students are included. These are treated in a qualitative way and not in a quantitative way. One reason for this is that when training industrial workers, the creation and use of control groups for statistical analysis usually is not in the interest of the companies involved.

Among Lean educators, there is consensus that education in Lean Production should contain significant elements of hands-on experience. Luttik for instance sees application of Lean principles, tools and methods during training/education as an important link in transfer of Lean Production training from education to the workplace [2]. Whilst many initiatives exist where factory-like environments are built within a university, Martin and Wilson report on an initiative where instead students spend significant time of their Lean education in industry, a concept which they call "Faculty on the Factory Floor" [3]. Full scale or near full scale simulation environments for game-based Lean education and training are relatively common. They include simulators based on assembly of pedal cars or wheel barrows. A simulator that includes materials processing simulation as well as assembly is Karlstad Lean Factory (KLF) which is described in more detail in earlier work by the Authors [4, 5].

2. Game-based Lean education and training

An important aspect of game-based education and training, like most other training and education, is how much of the training/education can be applied by the learner in a current or future work environment. This is usually called "training transfer". Luttik describes it as "That almost magical link between classroom performance and something which is supposed to happen in real world" [2]. Miller [6] suggests that training transfer generally increases with increased simulator fidelity (the degree of similarity between the training environment and the real environment). However, high fidelity simulators tend to be expensive and sometimes too detailed. The importance of a realistic game context, in particular for more experienced workers, is also acknowledged by for instance Pourabdollahian et al. [7], Messaadia et al. [8], and Dudovska-Popovska et al. [9]. However, for novices, the training environment should not be too complex and sophisticated as this makes it difficult for the participants to grasp and understand the game, or to see the correlation between their actions and the results [10, 11, 12]. Another disadvantage of detailed simulators is that simulator briefing may take too much time which can result in time pressure during a session [13]. On the other hand, the game context should not be too simple either as in that case, participants can perceive the game tasks as unchallenging and meaningless [9, 14, 15].

This balance between too simple or too difficult games is described by Kolb [16]. If the task is too difficult for the participant, the participant gets frustrated or feels anxiety. If the task is too trivial or simple, the participant gets bored. In between, there is a zone "flow channel" in which the participant is engaged in the task. In more recent work [17, 18], this zone is divided into two zones. One zone is called the comfort zone. In this zone, skills and insights are consolidated and confidence increases. The other zone is the challenge zone in which the game difficulty is stepped up. Learning takes place by zig-zagging between these two zones. One complication however may be that what may look like a simple game to an experienced Lean educator may actually be too abstract for some participant groups (i.e. the game "makes no sense" to them).

Game-based Lean production training and education can be seen as a form of serious gaming. Since serious gaming is a form of simulation [19, 20], it seems relevant to explore similarities of game-based learning with simulation. One way to describe simulation is the following [21, 22, 23]: Simulation means that first, a model of a so-called system of interest (SoI) is created through abstraction and idealization. Experimenting with the model yields simulation results, which in some way represent the behavior of the SoI. The suitability of the model depends on how well the simulation results correspond with the behavior of the SoI. Whether a model is seen as correct and valid depends on the *intended purpose*, i.e. the nature of the problem that gave rise to simulating the SoI.

Similarly, one can consider a Lean game to be an abstraction and idealization/simplification of (a part of) a production facility [4]. From desired skills and competencies in the students' envisaged future work environment, *learning objectives* can be derived (Figure 1, to the left). Experiential learning will result in *learning outcomes*. Debriefing, reflection and peer discussion can serve to align learning outcomes with learning objectives. The suitability of a simulator for game-based Lean education would thus be determined by how well the learning outcomes correspond with the learning objectives, the intended purpose of the education. However, compared to (computer) simulation, game-based learning has an additional factor and that is the *participant* or *participant group*. For industrial workers, a much better measure for the suitability of a simulator would be the training transfer from the simulation to their real world work environment (which students lack). This is shown in Figure 1, to the right. Different participant groups using the same simulator tend to exhibit different training transfer. Thus, the suitability of a Lean training simulator depends not only on the purpose of the training, but also on the participant group.

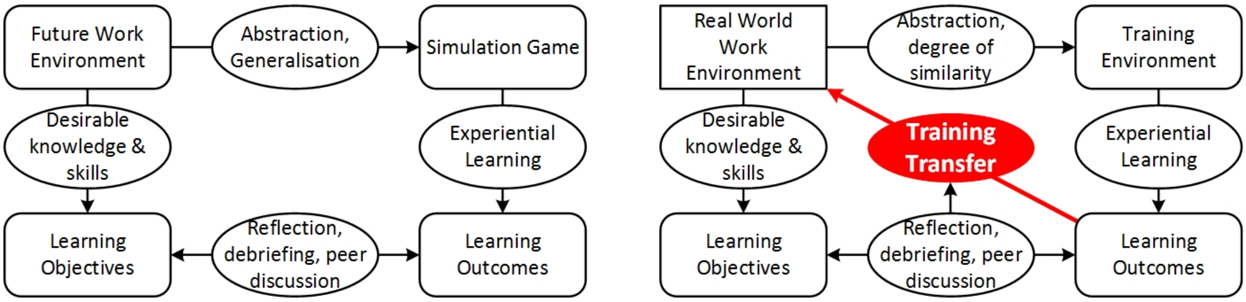

Fig. 1. Models for game-based Lean education/training for students (left) and for industrial workers (right)

3. Simulators for game-based Lean education and training

Simulators for game-based Lean education and training range from simulators incorporating actual manufacturing machinery to desktop games such as LEGO®-based games or paper-based games. Below, some types will be discussed followed by some examples of unique simulators.

3.1. Simulator types

Without claiming that the overview below is exhaustive, the following main types of simulators can be distinguished:

Teaching Factories (also called "Mini-Factory" or "Learning Factory"). This type of simulator consists of real manufacturing machinery. They are very similar to a real industrial environment. Examples are given in a.o. [24, 25, 26]. A potential disadvantage is that they are relatively inflexible and very specific for a certain type of production [27], and their high level of detail may render them less suitable for novices. Due to their nature, they are stationary. There is a certain risk for equipment specific improvement suggestions from the participants. They are usually suitable for training experienced machine operators, which highlights the importance of the participant group.

Full-scale and near full-scale simulators. This type of simulator usually contains "workstations" that are almost full-size. Examples of such simulators are pedal car assembly lines and wheelbarrow assembly lines. A disadvantage of many of these simulators is that they typically focus on assembly. The product components tend to be bulky, which is a limitation when transporting them. For this reason, most of these simulators are used at a fixed location.

Desktop games based on for instance LEGO® or similar products such as the "Muscle Car" simulator [7]. These games are popular not in the least due to their portability. However, they tend to be fairly abstract and it is an advantage if game participants are used to working with abstractions and analogies. Unfortunately, many university students lack exposure to industrial manufacturing environments and this can make it difficult for them to see the analogies. Desktop games can be used to teach some basic concepts, but for experienced workers, the games lack sufficient realism [9]. Another disadvantage is that change efforts are not always realistic [28]. This can result in improvement suggestions which would not be realistic in a real work environment.

Paper-based games. These are often used as shorter exercises to elucidate one or a few aspect(s) of Lean Production. They are inexpensive and an additional advantage is that participants can play game rounds even without the presence of an instructor/trainer, in some cases even at home if a computer-based score sheet (e.g. in Excel) is made available. A disadvantage can be that some games are perceived as fairly abstract; for instance the use of dices to simulate variability in demand and/or in processes is not always well-understood by all participants.

3.2. Some examples of unique simulators

Aures [29] describes a rather unique simulation game used at AUDI AG. He emphasizes that a suitable game has two characteristics: It must be far away enough from the real work environment to be a game, but close enough for training transfer. Furthermore, a list of elements to train/teach must be made upfront and the game should contain elements that can deliver this training. As an example, he describes a game developed and used at AUDI AG. This game mimics mass-customization of cars and takes the form of customer-configured sandwiches in a sandwich bar. Some of the challenges he mentions is the question of how and when to integrate theory with the game, how much help the trainer should provide to get the participants to the next step in the game, and how to react to unexpected solutions. Although in this case, the game context may not seem to resemble the work environment at first sight, it has been carefully designed so as to contain similar elements as production of mass-customized cars. Seemingly, it is a low fidelity simulator (to use Miller's terminology [6]), but actually it has surprisingly large similarities to the work environment due to the careful consideration of some key characteristics. However, this also makes the simulator relatively inflexible. It is claimed to stimulate creativity [29].

Another unique simulator is Karlstad Lean Factory (KLF). It consists, like the fairly popular pedal car assembly simulators, of near full-size workstations. One essential difference is that not only assembly, but also materials processing (either single item processing or batch/kit processing) can be simulated. Furthermore, cycle times and availability of the stations are adjustable. Other realistic features include stack lights and modular fixtures (Figure 2). The "standard" product is a modified IKEA children's chair in one or two colors (depending on the game scenario); special variants can be created by combining the colors in one chair. Moreover, it is possible to exchange this "standard" product for a product that would resemble a company's own product. Mobility is an important feature of the lab. This is confirmed by a survey amongst regional manufacturing companies and companies in the paper/pulp industry. Half of these (50%) prefer completely on-site training, with another 31% indicating that they would prefer an approach in which at least a part of the training would be on-site.

Fig. 2. Karlstad Lean Factory workstations with from left to right: single item processing station, batch processing station, assembly station.

4. Experiences from game-based training of students and industrial workers

Below, some experiences from game-based training are reported. Apart from observations made during training sessions, experiences include difficulties in assessing the effect of Lean education and training on individuals, and of training transfer into the participants' work environment and organization.

4.1. Experiences reported by Lean educators in general

Bicheno [30] mentions the need to focus Lean training more on teams and less on individuals. This is in line with TWI (Training Within Industry) where the focus is more on teams, but it is a complication factor when measuring the effects of training. Not in the least since Bicheno advocates combination of Lean training with for instance Agile, Operations Research, or TRIZ. Bicheno sees some analogies between major events in history and implementation of Lean Production. As success factors he identifies a.o. “an electric mix of skills” and “hierarchy downplayed” and as contributing factors to failure “ignoring simple but inconvenient evidence”, “silo thinking”, and “guarding own reputations”. The latter is also identified by Dieckmann et al. [13] as a barrier for successful Lean education; they call it “keeping up appearances” during a training session.

Michalicki & Blöchl [31] describe a technology center “PULS” in Landshut (Germany). They identify problems in evaluating competence transfer from lean simulation games. In particular, they state that there only are a few empirical studies of learning effectiveness in the field, as well as that measurement of competency development tends to be subjective.

This problem of measuring and quantifying learning and training transfer is also discussed by Hambach et al. [32]. They have found that there is no direct correlation between students exhibiting good knowledge at written exams and their problem solving skills in general or Lean competencies in particular. However, they found that students with poor exam results still demonstrated better Lean competencies than one might otherwise expect, an effect that Hambach et al. attribute to the social interaction during Lean games.

Michalicki & Blöchl [31] identify three main steps in game design: (i) identification of desired competencies with the activities that would develop such competencies, (ii) the creation of a scenario where such activities can be trained through repeatedly carrying out them, and (iii) communication of the starting scenario and scenario targets to the participants. Here, “starting scenario” is in line with the Authors’ opinion that one relatively unique aspects of Lean simulation games is that the participants change the game characteristics between game rounds. Their approach is to let teams do a pre-training test followed by a training day, a second training day about 4 weeks later followed by a post-training test and interviews some 4-8 weeks after the completed training. They note large differences between teams. Some teams made a progression of over 40% between the pre-training test and the post-training test, whereas other teams improved less than 7%. They also found that there is no significant correlation between a participant’s game role (such as assembly, quality assurance, or logistics) and the learning outcome.

Van Elp et al. [33] are Lean educators in the field of Healthcare. They find, contrary to what they expected, no evidence that the longer teams work with continuous improvement (CI) principles, the more mature the approach becomes. They also identify differences in maturity between teams. They claim that these differences are only weakly related to the time a team has worked with CI. They identify leadership style as a more important factor: A mix of a transformational and a transactional leadership style tends to result in a much more mature approach than a single-sided leadership style.

Rook [34], also a Lean educator in Healthcare, mentions that a questionnaire or exit poll may be used to assess *perceived* training transfer, but that assessment of *actual* training transfer from Lean programs is much more difficult. She reports questionnaire comments from participants that indicate barriers at the workplace to successful training transfer and Lean implementation related to work load and to reluctance amongst colleagues. Other comments indicate issues regarding communication between managers and workers resulting in poor motivation.

Allert & Säfsten have conducted a survey amongst 27 manufacturing companies [35]. They used a questionnaire and found that the effects of Lean education and other interventions (support during improvement initiatives) differ significantly between companies, even although they only studied small to medium sized manufacturing companies from one geographic region within Sweden.

4.2. Experiences from Karlstad Lean Factory

The authors of this paper have experience from both various desktop games and Karlstad Lean Factory (KLF). When we compare the two, then participants’ are much more engaged in the game when using KLF. For instance, we have noted that some student groups actually prepared themselves by observing other groups playing the game.

Also, older student cohorts have commented "why could we not use KLF instead of LEGO® when we did this exercise?". A similar effect has been observed when training industrial workers. When using KLF, "redundant" operators stay engaged in the game whereas with desktop games, there is a tendency that at least some start to do other things (like checking e-mail) without paying real attention to the game. Desktop games can be used to elucidate some basic Lean concepts to those who already have some theoretic knowledge about Lean, such as university students or white collar workers. Although it is never trivial how and when to weave in theory in a Lean game [29], it definitely becomes more difficult to convey Lean theory when using a desktop game, as compared to using KLF. Industrial blue collar workers in particular have problems understanding simulated variability in desktop games (for instance, the use of dices to simulate variability in demand or in process capacity), but even others including students do not always grasp this. Simulated availability through variable MTBF (failure intervals) and MTTR (repair times) is usually accepted as realistic and "natural" equipment behavior. For operators, one particular eye-opener usually is to run a simulation round with reduced cycle times, only to find out that this reduced cycle time hardly has any effect when no other improvements are made. A similar effect has been identified by De Zan et al. who mention comments such as "The training changed the way I saw the factory" [36].

When using KLF, it is also easier for participants to form an overall picture of what's going on around them due to the better visibility of disruptions in the production flow (such as pile ups, waiting, and blocking). The latter is supported by feedback from participants that visualization is superior to that of tabletop games and that the system provides more feedback. Some comments included that playing several rounds in Karlstad Lean Factory might also help to understand LEGO® based games better. This is in line with the Authors' intention to use the lab in combination with other training and teaching methods.

Like others [31, 35], the Authors have noticed large differences between companies and even between groups from within one company. In this respect, it is useful to have a discussion upfront with the companies regarding their specific training needs, who they want to attend the training, and why. This makes it easier to prepare the trainer for a training session, but also to stimulate awareness within the company. This reduces the risk that some participants "just go through the motions", as also noted in [34]. Differences within groups, not uncommon when training a group industrial workers, puts additional demands on the trainer. For instance:

- Non-native speakers or participants from an underrepresented group (e.g., female shop floor workers) may sometimes encounter difficulties to participate in the peer discussions. Instructors need to be vigilant for this.
- Managers may sometimes tend to push their own ideas too hard and as a result, won't let operators participate in the discussion properly. In this case, the instructor needs to act.

It is not unusual for groups to suggest unexpected and creative improvements; these are not always easy to accommodate. However, it is a sign that the simulation environment stimulates creativity and that participants make observations that they may not make in a more traditional environment or during a desktop game. Aures [29] reports a similar effect. In general, participants tend to be eager to try out things that they would not dare to try out in their work environment.

Dukovska-Popovska et al. [9] suggest to divide the participants in at least two teams in order to create competition. The Authors' experience is that this can move the focus away from actual improvement, and in particular students tend to create non-sustainable work situations or focus on optimizing their "game score" for instance through the inverse hockey stick effect. However, both effects can be used by the trainer to weave in theory in the simulation game. There is another benefit of playing with two or more teams and that is that it demonstrates that significant improvements can be made through different approaches. It is usually an eye opener for students that there is no "model solution" (which they sometimes ask for). It also demonstrates that the participants have a large influence on how the game scenario evolves.

When training industrial workers, the Authors use an extended debriefing to grasp how much the participants have learned during the training session, as well as for feedback. However, other means such as a questionnaire, "homework" or follow-up interviews a few weeks later would be suitable as well. The problem of measuring the effects and transfer of Lean Production training was mentioned by several speakers at the European Lean Educators Conference held in Nijmegen, November 2017, a.o. [20, 31, 32, 34, 37]. De Zan et al. [36] propose a methodology to map explicit knowledge against lean techniques. However, measuring tacit knowledge and skills acquired as well as measuring effects on companies/groups (rather than on individuals) remain challenges [34].

5. Suggested directions for developing lean education as a research discipline

In previous work [4], the Authors have presented five hypotheses for future research, namely (i) factory workers generally are a more diverse participant group than university students, (ii) for simulators in the low to medium fidelity range, training transfer for factory workers is lower than for university students, (iii) for low fidelity simulators, training transfer does not occur for factory workers, (iv) for high fidelity simulators, training transfer for factory workers can surpass training transfer for university students, and (v) for novices in manufacturing, high fidelity simulators are less suitable as they reduce training transfer due to their complexity and level of detail.

From the Authors' own experiences and experiences from other delegates at Lean Educator conferences, there is some (but definitely not conclusive) support for the first three hypotheses. There is some support from literature for the fifth hypothesis. However, confirming or rejecting the hypotheses will require much more work and as stated earlier, this will be beyond the capacities of a single research group.

It has also been suggested by the Authors that methods to assess training transfer and absorption of Lean principles might have to be reviewed and standardized [19]. The general impression from Lean Educator conferences is that other researchers and practitioners share this view, in particular since focus tend to shift from education individuals to training groups [30]. One complicating factor might be that Lean training of industrial workers is relatively often carried out by consultants. Whilst many of these consultants have a genuine interest in developing Lean Education as a discipline, the majority still stay out of the limelight which means that many valuable experiences and insights are not shared with other Lean Education practitioners and researchers. Van der Merwe [39] also mentions the problems of anecdotal evidence and groups working in relative isolation. Another complicating factor might be that combination of various teaching/training methods (as advocated in a.o. [30, 36]) makes it difficult to identify the effects of individual teaching/training methods. However, whilst measurement of absorptive capacity is regarded as complicated, it is also highly relevant, in particular with respect to SMEs [38, 40].

6. Conclusions

In game-based Lean Production training, it is important to use a training environment that is suitable both for the intended purpose of the training and for the participant group. Simulators must exhibit behavior that is perceived as "natural". Full-scale simulators have the advantage that they are similar enough to a real work environment to stimulate engagement of the participants whilst still being flexible enough to represent different work environments. In particular industrial workers can benefit from this as they can relate to their work environment. Measurement of Lean Production training effects has been identified as a topic for future work, in particular assessment of training effects on groups or organizations rather than on individuals. Current methods/tools are subjective and not uniform, hence it is proposed that they should be developed by the Lean Educators community as a whole.

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