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Can gamification help to improve education? Findings from a longitudinal study

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ABSTRACT

A goal of any educational measure is to improve students' capability to retain teaching content. In this paper, we investigate the potential of gamification to foster knowledge retention using an action research approach. We present the results from a longitudinal study including 617 secondary and tertiary education students conducted over a period of two years. Various workshop designs that incorporated numerous gamification elements were compared with non-gamified workshop designs, tested and refined over time. The improved workshop designs led to increased levels of knowledge retention that exceeded the benchmark values from educational literature. We found that gamification exerts a positive impact on knowledge retention. We tested for the moderating effects of gender and age and found no effect of the former and inconsistent results for the latter. The steady increase in students' learning performance resulting from constant refinement of the workshops demonstrates the usefulness of incorporating gamification principles into educational activities.

1. Introduction

Previous research has lamented that "the challenge of teaching has increased when faced with increasingly apathetic students" (Wood & Reiners, 2012, p. 101). The so-called generation Y, born between 1980 and 2000, is considered particularly hard to motivate when traditional teaching methods are applied. Despite continuous efforts by educational professionals to apply novel and innovative teaching practices, numerous students perceive traditional schooling as boring and ineffective (Lee & Hammer, 2011). More specifically, Grabinger and Dunlap (1995) found that traditional teaching does not foster students' capability to solve problems autonomously or to transfer learning content to new situations. Educators have therefore identified a need for the refinement of teaching methods that tackle the challenge of efficient knowledge transfer, student engagement, as well as optimal transferability of course contents and problem solving skills. Students themselves prefer engaging and interactive learning activities (Kiili, 2005). As a potential solution, gameful learning has gathered increased attention from the education sector, as well as academia and industry, since it promises novel opportunities to foster skills and increase knowledge. Gameful learning is considered a form of experiential learning that presents a potential solution to addressing student motivation and improving problem solving skills by increasing their level of involvement (Lee & Hammer, 2011).

A promising enabler in education is gamification, which is defined as "using game-design elements in any non-game system context to increase users' intrinsic and extrinsic motivation, help them to process information, help them to better achieve goals, and/or help them to change their behaviour" (Hamari, Koivisto, & Sarsa, 2014; Treiblmaier, Putz, & Lowry, 2018, p. 134). Previous research has shown that gamification can foster intrinsic motivation (Goh, Pe-Than, & Lee, 2017; Hamari & Keronen, 2017), make learning more engaging (Gatti, Ulrich, & Seele, 2019; Çakıroğlu, Başıbüyük, Güler, Atabay, & Yılmaz Memiş, 2017), and increase students' knowledge retention (Dicheva, Dichev, Agre, & Angelova, 2015; Majuri, Koivisto, & Hamari, 2018). Tsay, Kofinas, and Luo (2018) found that students are slightly more engaged in a gamified than a non-gamified environment. Other authors have illustrated that the educational use of games and game elements triggers students' active learning processes, which subsequently improves their knowledge retention: a major goal of all learning activities (Gatti et al., 2019). Skills that are acquired during gaming are sometimes even considered as relevant technical and social capabilities for jobs. Thus, the image of 'traditional gamers' has drastically changed in recent times, which opens the door for the acceptance of games in various fields such

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Table 1
Educational and longitudinal research.

Database	Results					Ratio
	ES	LS	ES using LS	LS in gamification	LS in gamified education	Share of LS in education/education studies
EBSCO	138,962	24,953	2824	3	0	2.03%
ScienceDirect	104,639	82,748	3018	7	3	2.88%
IEEE Xplore	43,862	6010	140	1	0	0.32%
Emerald Insight	9716	2119	244	0	0	2.51%
GoogleScholar	>1,200,000	>219,000	1380	3	1	<.001%

ES: Educational Studies.
LS: Longitudinal Studies.

Table 2
Longitudinal studies in gamification.

Research focus	Game elements	Findings	Gamification effect	Source
Tertiary education (English)	Leaderboards, badges, challenges, group competition	Game elements can support different motivational types; potential to counter the downward trend in students' autonomous motivation; personal characteristics mediate between gamification and motivation	Positive	Van Roy & Zaman, 2018
Tertiary education (emergency medicine)	Levels, badges, rewards	Increased learning activities in gamified groups; positive correlation between students' grades and online participation; positive effect on creating a community of practice between teachers and students	Positive	Grangeia, Jorge, Cecílio-Fernandes, Tio, and Carvalho-Filho (2019)
Tertiary education (communication)	Leaderboards, badges, competition	Gamification decreases motivation, satisfaction, and empowerment	Negative	Hanus and Fox (2015)
Tertiary education (Instructional technology and material development course)	Among others: Leaderboards, badges, rewards, challenges, storytelling, cooperation, points, avatars, levels	Challenges should provide several types of difficulty, timing and frequency to provide freedom of choice; varying effects of different game elements	Positive	Aldemir, Celik, and Kaplan (2018)
Web survey with online questionnaire	Storytelling, points, rewards, feedback	Promising motivational effect in first phase faded in the second phase; gamified group had a higher survey dropout and higher level of distraction	Mixed results	Mavletova (2015)
Online social idea competition	Game Points, social points, levels, storytelling, avatars, feedback, badges	Game mechanics perceived as motivating; game elements with social character increase participants' status; storytelling and avatars had lowest motivational impact	Slightly positive	Scheiner (2015)
Users from co-creation platform	Cooperation, competition, rewards	User types react differently to gamification mechanics; gamification is a valuable means for designing smart technologies to create, boost, and maintain users' engagement	Positive	Leclercq, Poncin, and Hammedi (2017)
Sports - Walking app	Levels, freedom of choice, feedback	Gamification supports behavioural change; no significant effect on intrinsic motivation	Slightly positive	Mitchell, Schuster, and Drennan (2017)
Sports - Fitness tracking study	Leaderboards, badges, points, achievements, rewards, likes, cooperation	Game elements increasing social value had a stronger positive impact on the number of steps (i.e., workout) than those enhancing emotional values	Positive	Tu, Hsieh, and Feng (2019)
Health science (mHealth)	Levels, achievements, rewards, likes	Gamification as a low-cost and highly-effective tool for behavioural support in smoking cessation programs; three critical factors for game engagement: purpose, user alignment, functional utility	Positive	El-Hilly et al. (2016)

as learning or capacity building (Petter, Barber, Barber, & Berkley, 2018).

Scant research has been conducted on gamification and knowledge retention (Majuri et al., 2018). Research specifically addressing the questions of if and how gamification can lead to increased knowledge retention therefore remains scarce to this day. A notable exception is an empirical study from Buckley and Doyle (2017) with more than 100 participants, which shows that gamification has a positive impact on student knowledge retention if individual learning needs and personality traits are considered properly. A further open question of central importance is whether gamification has the potential to positively influence students' knowledge retention in the long run (Osatuyi, Osatuyi, & de la Rosa, 2018; Seaborn & Fels, 2015). Longitudinal studies about gamification and knowledge retention need to be carefully designed in order to avoid previous shortcomings of gamification research (Liu, Santhanam, & Webster, 2017), which in particular pertains to tailoring the gamification elements to the needs of the target group (Höllig, Tumasjan, & Welpe, 2018; Wolf, Weiger, & Hammerschmidt, 2020).

In this paper, we investigate how the knowledge retention of secondary and tertiary educational students can be improved using gamified workshops. These workshops were full-day events, organised as field trips and enriched with game elements, to train students in the basics of sustainable supply chain management. We conducted a longitudinal experiment comparing gamified and non-gamified groups, including age and gender as moderating variables.

In the following section, we briefly discuss the prominence of educational and longitudinal studies in academic research with a special focus on gamification. We then develop five hypotheses that postulate a positive impact of gamification on knowledge retention and consider age and gender as moderating variables. In the methodology section, we elaborate on the design of our workshops, which was adapted over time to accommodate students' needs. Given that the purpose of this longitudinal study was to improve educational quality, we followed an action research approach (cf. Checkland & Holwell, 1998) and modified the design of the workshops to better accommodate students' needs. In the subsequent section we present the results, followed by the testing of the

hypotheses and a comprehensive summary of our findings. We conclude the paper by highlighting several limitations that might also serve as a basis for future research.

2. Literature review

To investigate the current academic status of educational and longitudinal studies we conducted a literature review with a special focus on gamification. The review was carried out in November 2018 using the databases EBSCO Business Source Elite, ScienceDirect, IEEE Xplore, Emerald Insight, and Google Scholar. We used the search terms "longitudinal", "education*", and "gamif*", and various Boolean combinations thereof (Datta, 2017). The search was limited to metadata, which included titles, abstracts, and keywords. We modified the search terms to the variety of filter options and potential wildcards in the databases. The used search terms can be found in table A1 in the appendix.

Table 1 gives an overview of current academic literature pertaining to educational and longitudinal studies. While a substantial amount of research into education exists, only a minority of these publications uses longitudinal studies (column: ES using LS). In total, ten longitudinal studies dealing with gamification where found, with only four discussing educational topics.

The ten longitudinal studies in gamification are briefly discussed in Table 2, showing the research focus, the game elements being used, the major findings, and the overall effect of gamification.

The gamification studies listed in Table 2 found predominantly positive effects of gamification in terms of both cognitive and behavioural outcomes. In fact, eight of the ten studies yielded positive or slightly positive motivational or performance-related results, while one study found mixed results and only one obtained negative results from using game elements. The game elements used in the studies vary widely, with badges, rewards, leaderboards, and points being mentioned most frequently.

The findings of the four longitudinal studies which combine gamification and education highlight the potential of gamification to increase students' motivation and engagement as well as to boost their performance. Three out of four studies report of positive results. In their study lasting 15 weeks, Van Roy and Zaman (2018) investigated the importance of personal characteristics and their mediating role between gamification and motivation. Over a period of five years, Grangeia et al. (2019) showed that gamification can be used in combination with social media to foster the creation of a community of practice and to increase learning activities. Aldemir et al. (2018) studied various alternatives of game elements for one academic year and emphasised the importance of the complexity of each respective element, which is reflected in diverse perceptions from students. The critical findings from Hanus and Fox (2015) illustrate that extrinsic motivators such as rewards, badges, and leaderboards need to be carefully chosen and adapted to the needs of students in order to avoid a detrimental effect.

Additionally, we found that studies on the use and effects of gamification in a workshop setting are scarce. One exception comes from Johnsson (2018), who compared gamified workshops with non-gamified ones in terms of their capacity to generate innovation. The results indicate a higher capability for self-learning in the gamified group. Another example is a multiple case study by Parjanen and Hyypiä (2019), who used gamification in co-design workshops as a tool to enhance individual and collective creativity. Their results show that gamification can foster the process of creativity by building a safe and creative environment for ideation and therefore reducing social distance. Summarising, the majority of findings indicate that gamification offers considerable potential as a positive emotional, cognitive, or behavioural stimulus. Nonetheless, there exists a dearth of longitudinal studies that rigorously investigate the impact of gamification in education.

3. Hypothesis development

A sustained increase in knowledge is a major goal of educational measures. It is therefore highly desirable that the teaching content is fully understood and retained by the students for as long as possible after the educational event (Murre & Dros, 2015). The classic forgetting curve of Ebbinghaus (1913) has been the benchmark for knowledge retention research for decades. It assumes a 100% recall of the learned content immediately after a learning event and 58% after 20 min, which corresponds to the timing of the second assessment in our workshop designs. The retention rate is predicted to be about 25% after two weeks, which corresponds to the third assessment in our design. In this paper, "short term" therefore refers to the period of about 20 min immediately after the workshops and "long term" refers to a period of two weeks after the workshops.

Gamification has previously been applied in education to encourage specific behaviours as well as engagement and motivation. For example, Blohm and Leimeister (2013) found that people changed their behaviour when applications were enriched with game elements. It has also been used for teaching purposes to help educators broaden the variety of teaching methods to motivate students (Huang & Soman, 2013). The overall intention of the application of gamification is to engage students in an interactive setting, ultimately leading to better memorization (Kapp, 2012).

The systematic mapping study from Dicheva et al. (2015) about the impact of gamification on education yielded a positive impact in the majority of the reviewed studies. In a nutshell: gamified teaching results in active participation, more project engagement, increased attendance, and a higher proportion of students passing the course. Dias (2017) reports findings from an experiment comparing a non-gamified and a gamified group and found that gamification yielded positive results including an increase in class participation and course success. Moreover, students evaluated the gamified course better than its non-gamified counterpart.

Summarising the findings from previous research, we postulate that gamification, as implemented in our study in the context of a gamified workshop, is an appropriate tool to increase knowledge retention. More specifically, we hypothesize that students in the gamified group are able to retain knowledge better than students in the non-gamified group in both the short and the long term:

H1. In the short term, the gamified group has a higher level of knowledge retention than the non-gamified group.

H2. In the long term, the gamified group has a higher level of knowledge retention than the non-gamified group.

Previous studies of gender differences pertaining to cognitive functioning and knowledge retention show conflicting results. Some studies indicate that female students outperform male students in terms of knowledge gains (Kılıç & Sağlam, 2010; OECD, 2015; Van Houtte, 2004). One potential explanation is that female students have a stronger study-oriented learning culture, which has a positive effect on knowledge retention (Van Houtte, 2004). Accordingly, Legewie and DiPrete (2012) postulate that male students are more affected by their school environment and may associate anti-school attitudes. As a result, males are more sensitive than females to school resources able to create a learning-oriented environment that promotes their learning engagement. In addition, gender-specific performance also appears to depend on the subject matter. While females outperform males in tests involving memory and language use, males show better results in terms of visuospatial abilities and mathematical reasoning (Downing, Chan, Downing, Kwong, & Lam, 2008). Other studies claim that gender is not a factor for knowledge retention, but rather for learning strategies and cognitive styles (Chen, Yang, & Hsiao, 2016). In light of the conflicting results concerning the moderating effect of gender on learning performance in general, we hypothesize no effect:

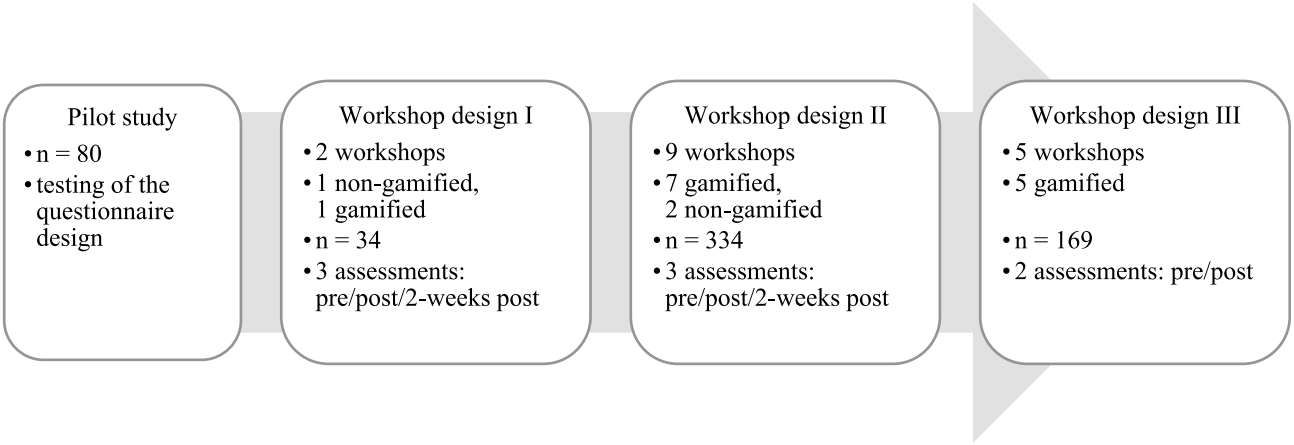

Fig. 1. Longitudinal gamification study design.

H3. The level of knowledge retention in the gamified group does not differ between male and female students.

Previous research regarding the effect of age on students' learning is also inconsistent. While some researchers have found age to be an explanatory factor for academic performance (Navarro, García-Rubio, & Olivares, 2015), others have concluded that ageing does not impact academic achievement (Imlach et al., 2017). In order to test the effect of age on knowledge retention, we differentiated between traditionally and non-traditionally aged students (Gotschi, Vogel, Lindenthal, & Larcher, 2009; Seiler, 2011). In our setting, traditionally aged students are between 15 and 19 years old, while non-traditionally aged students are 20 years and older. Given the inconsistent findings in academic literature regarding the effect of age on learning performance, we hypothesize no effect:

H4. The level of knowledge retention in the gamified group does not differ between younger and older students.

The gamified workshops were embedded into a general action research framework with the goal of motivating students and thus improving knowledge retention (Checkland & Holwell, 1998). Over the course of the study, the workshop design was subject to a number of alterations intended to improve the overall learning experience (Santini, Marinelli, Boden, Cavicchi, & Haegeman, 2016). The alterations, based on qualitative feedback from lecturers, students, and industry partners, as well as empirical survey data received from students, involved the addition, removal and modification of game elements. The design changes, which are described in more detail in the section on study design, included the introduction and modification of game elements as well as the improvement of the measurement instrument and were implemented with the goal of increasing knowledge retention. Therefore, we hypothesize:

H5. Adapting the workshops to students' needs leads to an increased level of knowledge retention.

4. Methodology

Following recommendations from previous gamification literature (e.g. Nacke & Deterding, 2017; Osatuyi, Osatuyi, & de la Rosa, 2018) we conducted a longitudinal gamification study, ranging from June 2015 until May 2017. In total, 617 students from secondary education (i.e. higher education and vocational school students) and tertiary education (i.e. bachelor students) participated in the study that also included a comprehensive pilot study. We tested for statistical differences between secondary and tertiary education within one workshop design and found no differences. Thus, the secondary and tertiary students in our sample can be considered as having a similar level of pre-existing knowledge concerning sustainable supply chain management. For our longitudinal study, we used quantitative data to test our hypotheses. In fact, we run an experimental design including control groups (i.e. non-gamified workshops) for workshop designs I and II to investigate whether significant differences in knowledge retention existed between students who participate in gamified workshops and students who are not exposed to gamification. As both workshop designs yielded a positive impact of gamification on knowledge retention, we decided to no longer use a control group (i.e. non-gamified group) as we moved on to workshop design III, and focused instead on changes in the gamification design. Fig. 1 summarizes the development process of the design including the number of participants for each workshop design and the respective types (gamified/non-gamified).

The experiential longitudinal study included a gamified and a non-gamified workshop group for workshop designs I and II, with knowledge assessments taken at three points in time: immediately before (A1), 20 min after (A2), and two weeks after (A3) the workshops. We selected these specific points in time for comparison with measures based on learning retention theory by Ebbinghaus (1913), which has been successfully replicated (Murre & Dros, 2015). To ensure comparability between assessments, we used identical knowledge questions for the three assessments in each workshop and made sure that they were not anticipated by the students. In other words, the students were not aware that they would be tested repeatedly in order to assess their level of knowledge retention, such that all three assessments were a surprise to them.

All participants were recruited from upper school and university programs from various institutions (i.e. vocational schools, higher educational institutions, universities). The survey contained demographic questions and a unique, individual coding to ensure that the respondents could be correctly assigned to the three assessments in this panel study while guaranteeing students' privacy. The assessment instrument used to measure students' knowledge included questions of varying complexity and type (i.e. a mix of single choice and multiple choice questions) and was developed in close cooperation with industry partners to ensure that the knowledge has practical value. The generic structure of the assessment instrument can be found in Table A3 in the appendix. The answers had to be fully correct in order to be taken into account, resulting in the strictest grading possible and a very conservative estimate of the overall knowledge gain.

The goal of the workshops was to train students on topics related to sustainable supply chain management by combining theoretical and practical knowledge in a full-day event (i.e. as a field trip). We changed the workshop contents after each round according to the learnings we made and analysed the effects of the changes on knowledge retention under consideration of the moderating effects of gender and age. The instructors of the workshops stayed the same throughout the study in

Table 3
Demographics of the participants.

	Workshop design I			Workshop design II			Workshop design III
	Gamified	*Non-gamified*	*Total*	*Gamified*	*Non-gamified*	*Total*	*Gamified*
n	16	18	34	261	73	334	169
Age							
mean	25.19	24.61	24.88	18.73	26.34	20.54	18.22
sd	2.07	2.00	2.03	4.15	10.74	6.93	1.73
Gender							
male	12	13	25	161	13	174	67
female	4	5	9	100	60	160	102

Table 4
Knowledge assessments.

	Workshop I		Workshop II		Workshop III
	Gamified	Non-gamified	Gamified	Non-gamified	Gamified
A1					
m (sd)	0.97 (0.90)	0.86 (0.81)	3.32 (1.32)	3.15 (1.61)	3.46 (1.20)
n	16	18	238	66	169
A2					
m (sd)	5.83 (1.70)	2.78 (1.58)	6.57 (1.82)	5.06 (1.89)	7.04 (1.98)
N	16	18	230	67	169
A3					
m (sd)	3.17 (2.17)	1.39 (1.29)	4.97 (1.86)	4.52 (1.61)	–
n	7	8	204	37	–

Maximum possible value: 10. The number of questionnaires does not fully correspond to the number of participating students, since not all students filled out a questionnaire.

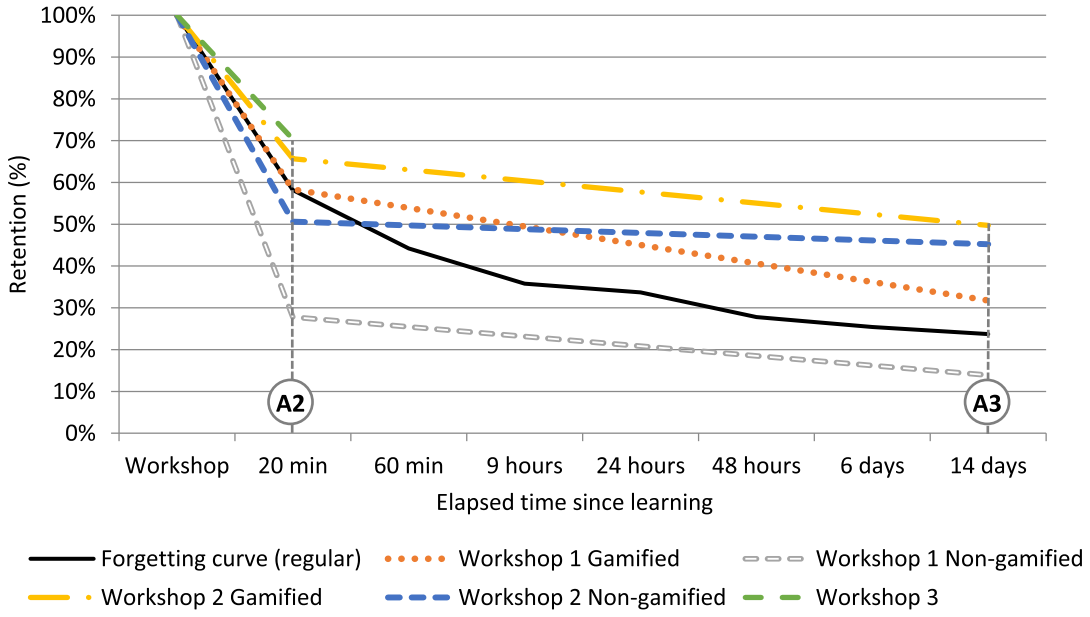

Fig. 2. The impact of gamification on knowledge retention.

order to eliminate any confounding influence. The workshop designs and schedules of the workshops are described in Table A2 in the apppendix.

5. Results

Following a pilot study with 80 students, 537 students participated in the three rounds of workshops. A total of 16 individual workshops took place, with 446 students assigned to gamified groups and 91 to non-gamified groups. The latter served as control groups by participating in traditional workshops lacking any game elements, but otherwise exhibiting the same structure as the gamified workshops. Table 3 shows the distribution of the study participants across the three workshop designs. The gender distribution in the longitudinal study was fairly balanced with 271 female and 266 male participants. In workshop design II the age differences were caused by a higher proportion of students re-entering the workforce in the non-gamified group from a vocational school.

Table 4 shows the descriptive results of the knowledge measurements for all three workshop designs. The maximum possible score was ten points and the standard deviation is shown in brackets. All three workshop designs exhibit the same pattern, with the knowledge level being lowest prior to the workshops (A1), reaching its peak at the second assessment (A2), and exhibiting a slight decline at the third assessment

Table 5
Summary of the hypotheses.

	Hypothesis	Workshop	Result
H1	In the short term, the gamified group has a higher level of knowledge retention than the non-gamified group	I + II	Supported
H2	In the long term, the gamified group has a higher level of knowledge retention than the non-gamified group	I + II	Rejected[a]
H3	The level of knowledge retention in the gamified group does not differ between male and female students	I + II + III	Supported
H4	The level of knowledge retention in the gamified group does not differ between younger (<20 years) and older students	II + III	Supported
H5	Adapting the workshops to students' needs leads to an increased level of knowledge retention	I + II + III	Partially supported

[a] It has to be noted, however, that the gamified group exhibited a higher level of knowledge retention in the long run, but that the results were not statistically significant.

step, we analysed the presence of knowledge differences prior to the workshops. A two-tailed Mann-Whitney *U* test showed that knowledge levels did not differ significantly between the gamified and the non-gamified group in the first assessments of workshop designs I ($U = 135$, $p = .74$) and II ($U = 7{,}253$, $p = .33$), which confirms the validity of the research design in which the respective groups were chosen randomly. Comparisons by age groups (<20 years, ≥20 years) and gender showed no significant differences regarding the level of prior knowledge in all three workshops designs. We therefore conclude that neither the sample selection process nor age or gender exhibited a significant influence prior to the conduction of our studies.

In order to test H_1 and H_2, which postulate a significant positive effect of gamification in the short and long term, respectively, we used a one-tailed Mann-Whitney *U* test. In the second assessment, the gamified group outperformed the non-gamified group in both workshop design I ($U = 28$, $p < .01$, $r = 0.70$) and workshop design II ($U = 4{,}312$, $p < .01$, $r = 0.32$), corroborating H_1. In the third assessment, the mean values in the gamified groups were higher than that in the non-gamified groups, but the differences between the groups in workshop design I ($U = 14$, $p = .12$) and workshop design II ($U = 3{,}246$, $p = .17$) were not significant.[1] Therefore, H_2 is rejected.

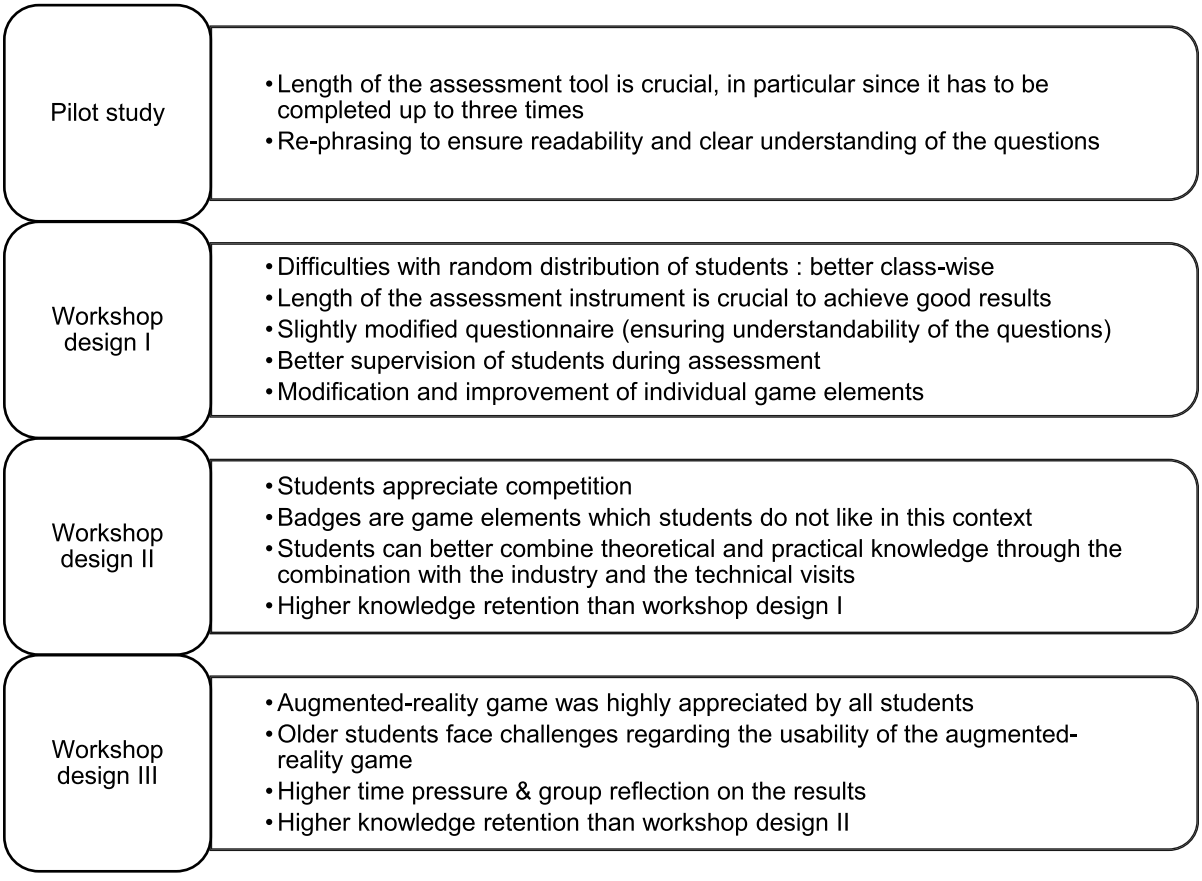

Fig. 3. Summary of lessons learned.

(A3) (see also Fig. 2). The rate of valid assessments at A1 was 94%, at A2 93% and at A3 70%, with the assessment at A3 applicable only to workshop designs I and II. The knowledge differences between the groups prior to the workshops were only minor and not significant. The results regarding knowledge retention show that all the gamified groups outperform their non-gamified counterparts.

In the following sections we use several non-parametric tests for hypothesis testing which accommodate the properties of our data, such as non-normal distributions, skewness, ordinal levels of measurement, unequal sample sizes, and lack of homogeneity of variance. In a first

We used a Mann-Whitney *U* test to check for differences between genders in terms of knowledge retention in the gamified groups (H_3). In workshop design I, the test showed no significant differences in either the second ($U = 22.5$, $p = .85$) or third assessment ($U = 3.5$, $p = .56$). No significant differences were found for workshop design II in the second

[1] In the case of workshop design I this can be partly attributed to the small sample size.

Table 6
Used game elements in the gamified workshop.

Game element	Workshop implementation	Reference
Clear goals	The participants understood exactly the aims of the overall workshop and each respective task. They also knew the maximum number of points for each task.	Warmelink, Koivisto, Mayer, Vesa, and Hamari (2020) Kapp (2012) Liu et al. (2017) Hamari and Koivisto (2014)
Immediate feedback	The participants learned immediately if they had found the correct solution or what the correct solution would have been otherwise.	Warmelink et al. (2020) Kapp (2012) Siemens, Smith, Fisher, Thyroff, & Killian (2015) Reeves and Read (2009) Nah, Zeng, Telaprolu, Ayyappa, and Eschenbrenner (2014)
Leaderboard	The participants knew exactly how their team and the other teams were performing	Warmelink et al. (2020) Kapp (2012) Sailer et al. (2017) Mekler, Brühlmann, Tuch, and Opwis (2017)
Time constraint	For some tasks, e.g. in Logistify, the participants had only limited time available to find solutions.	Kapp (2012) Reeves and Read (2009)
Competition & cooperation	The workshop was designed in the form of a competition; the teams received points for correct answers or good solutions. Participants needed to collaborate within the teams to be able to solve the tasks.	Warmelink et al. (2020) Reeves and Read (2009) Sailer et al. (2017) Werbach and Hunter (2015)
Storytelling	The tasks were embedded in a story so the participants were motivated and got involved in this story.	Kapp (2012) Reeves and Read (2009) Langendahl, Cook, and Mark-Herbert (2017) Sailer et al. (2013)
Rewards & badges	The best team received a prize, a picture of the winners and a badge, which was sent after the workshop. Rewards were used to externally motivate the participants.	Warmelink et al. (2020) Kapp (2012) Sailer et al. (2017)

assessment (U = 5,630, p = .17) or third assessment (U = 4,629, p = .32), or in the second assessment of workshop design III (U = 3,267, p = .63). These results indicate that gender does not moderate the effect of gamification, and corroborate H_3.

In order to test the impact of age on knowledge retention in the gamified group (H_4) we compared the two age groups (<20 years, ≥20 years) with a Mann-Whitney *U* test. In the first round of workshops, only students over the age of 20 participated and no test was conducted. The results of workshop design II showed no significant difference in the second assessment (U = 3,726, p = .08) but a significant difference in the third assessment of the gamified group (U = 2,356, p < .01, r = 0.21), with the older age group outperforming the younger one. In workshop design III, there was a significant difference in the second assessment (U = 1,571, p = .02, r = 0.18) with the younger age group outperforming the older one. In light of these inconsistent results, H_4, which postulates no impact of age on the effect of gamification measures, is supported.

Fig. 2 shows the participants' level of knowledge retention in the gamified workshops in comparison to the forgetting curve from Ebbinghaus (1913). Immediately after the workshops (A2) the level of short-term knowledge retention from all three workshop designs exceeds the benchmark of the forgetting curve, and the gap widens with each design adaption. As compared to the benchmark of 58.2%, workshop design I resulted in a level of knowledge retention of 58.33%, workshop design II in 65.69% and workshop design III in 70.36%. A Mann-Whitney *U* test reveals significant differences between workshop design I and II (U = 760, p < .01, r = 0.25) but no significant difference between workshop design II and III (U = 18,100, p = .24). Similarly, the level of long-term knowledge retention at A3 (from workshop designs I and II) increases with each design adaption. With 31.75% in workshop design I and 49.73% in workshop design II, both workshop designs outperformed the benchmark of the forgetting curve predicting 23.72% recall. Furthermore, the difference between workshop design I and II is significant (U = 254, p < .01, r = 0.20). Therefore, H_5 is partially supported[2]. The hypotheses and the results are summarized in Table 5.

6. Discussion and implications

In this paper, we investigate the impact of gamification on students' knowledge retention. 617 students participated in a pilot study and three rounds of workshops that were incrementally improved in an action research approach. Following the pilot study, the workshops were redesigned after each round to better match students' needs and enhance the level of knowledge retention. In the first two rounds, we

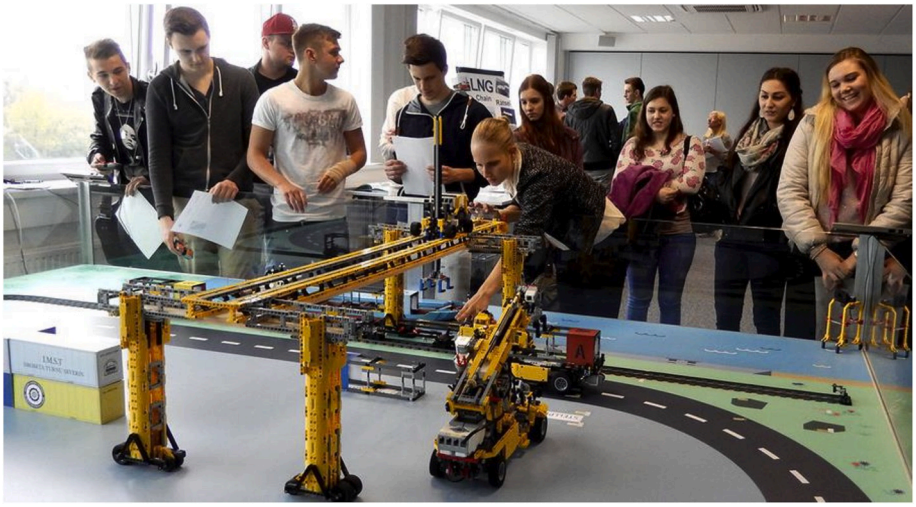

Fig. 4. Students playing games and learning using the LEGO simulation game.

[2] With the limitation that the improvement of workshop design III is not statistically significant at A2.

compared the gamified group with a non-gamified control group, which confirmed the positive effect of gamification in the short term (i.e. immediately after the workshop), but not in the long term (i.e. two weeks after the workshop). Although the gamified group outperformed the non-gamified group in the final assessment, the results were not statistically significant. The decrease in knowledge levels over time, which was to be expected from previous research (Murre & Dros, 2015), occurred slower in the gamified groups than in the non-gamified groups.

The examination of possible influencing factors showed that gender had no specific influence on the level of knowledge retention, which corroborates the findings from Chen, Liou, and Chen (2019). Differences between the age groups existed after workshop designs II and III, but the results were not consistent. One reason might be the use of digital content, which could be in line with the more technology-savvy younger generation (Bittner & Schipper, 2014). Most importantly, the results show that the changes of the workshop design led to improvements in both short- and long-term knowledge retention. This knowledge gain is visible across all workshop designs, both for gamified and non-gamified groups, but the effect is more pronounced in the gamified design.

Fig. 3 summarizes the learnings from the ongoing adaptation of the gamified workshops. Each new workshop design led to a further increase in knowledge retention. Thus, we argue that the modifications of the workshop designs, which were based on feedback from the students and their instructors, were successful in fulfilling students' needs. The main goal of the pilot study was the creation of a fair, understandable and unbiased assessment instrument. Workshop design I revealed that the separation of students from the same class disrupted the workshops and caused confusion. In addition, we had to slightly revise the assessment instrument used to measure knowledge retention to improve the readability of the questions. Based on workshop design II we received the feedback that the workshops organised as a whole-day competition in groups rolled by very quickly and that the participants experienced a high level of flow. Moreover, the students in the gamified group highly appreciated the combination of theoretical knowledge, active learning through games and the technical visits. One interesting finding was that not all game elements worked out equally well. For example, the students could not relate to the badges they received, which did not constitute a motivational factor. We therefore decided to exclude this game element in workshop design III. Moreover, we introduced an augmented-reality game. Interestingly, younger participants needed less time to familiarize themselves with the augmented-reality game in comparison to older ones.

In the following sub-chapters, the workshop designs and the variations based on the results including Fig. 3 are described in more details.

6.1. Implications for workshop design I

34 students were randomly allocated to non-gamified and gamified groups. Grouping students into teams served to reduce the negative effects of competition at an individual level and to support social interaction (Sailer, Hense, Mandl, & Klevers, 2013; Sailer, Hense, Mayr, & Mandl, 2017). The game elements for workshop design I were chosen by an expert panel that was responsible for the workshop design. The panel consisted of several experts (one from industry, one from supply chain management education, one from information systems (IS) and one with a major in IS and supply chain management). After a literature review of all potential game elements, the expert panel assessed the potential applicability of each element and created various realizations in line with the general goal of the workshop, namely the transfer of knowledge related to sustainable supply chain. The game elements used in the gamified workshops are shown in Table 6 and the workshop design is elaborated in more detail in Table A2.

Both gamified and non-gamified workshops had an identical structure, content and duration, but differed by the application of game elements. For example, all the students had to do the same calculations, but only received points for correct solutions in the gamified workshops. Similarly, students in the gamified groups got incentives for accomplishing each task, such as finding the correct solution in a simulation game. All tasks in the gamified workshops were embedded into a "story" to use the motivational advantages of storytelling as a game element (Kapp, 2012). Competition between the gamified groups was encouraged by showing the best student groups on the leaderboards. An exemplary description of a workshop and how several game elements were applied can be found in Appendix A4.

The results of a critical evaluation of workshop design I showed that a separation of students from the same course into different testing groups led to social interaction threats. Students did not concentrate on the underlying workshops, but focused instead on thoughts such as 'What are the colleagues in the other room doing? What happens there?' (Trochim, Donnelly, & Arora, 2016). In order to achieve a high level of internal validity, it was therefore essential that students and instructors did not know that there was another group which received an alternative treatment (Trochim & Donnelly, 2008).

6.2. Implications for workshop design II

Workshop design II was based on the previous workshop design I, but was slightly modified by incorporating the findings and the feedback we received. In general, the content and the tasks were identical to workshop design I. The major change was that instead of individual assignment to the gamified and non-gamified groups, we assigned the students class-wise. This was done in a randomized manner. In total, 334 students participated in seven gamified and two non-gamified workshops. The assessment instrument was – similar to workshop design I – distributed immediately before the workshop, 20 min after the workshop and two weeks later. Additionally, the individual game elements were refined and adapted to the students' needs.

6.3. Implications for workshop design III

In the third round, we conducted five gamified workshops with 169 participants. The assessments were conducted before and after the workshop, but not two weeks later. This was done since the previous two rounds had already confirmed the positive effect of gamification and it was our goal to provide the best educational model possible for the benefit of the students. Based on the results of the previous workshops, we also made some substantial changes in the design. First, the content and the presentation style of the interactive lecture was adapted to ongoing and novel developments in the field of sustainable supply chain management. Second, we excluded the game element "badges" and replaced one part of the workshop (i.e. transport calculation) by an augmented reality game called Logistify,[3] which used the following game elements: time constraints, avatars, points, clear goals, immediate feedback, and storytelling. Third, we shortened the time limits and included a discussion session about the learnings after the simulation game and the container quiz. The detailed program of gamified workshop design III can be found in the lower part of Table A2 in the appendix.

6.4. General implications for practitioners and researcher

As a practical implication, we strongly encourage educators to incorporate game elements into their teaching routine in order to foster students' knowledge retention levels. When designing gamified workshops, the didactical methods for covering content have to be chosen carefully with consideration of the demographics of the target group. According to flow theory (Csikszentmihalyi, 1996), information and

[3] Logistify is a learning application for supply chain management which can be played on smartphones and tablets. It illustrates topics such as transport choice, transport chains and logistics professions.

learning aims must be adapted to the age and educational background of the participants with the goal of achieving an adequate level of difficulty that is neither too easy nor too hard. Table A2 in the appendix illustrates which game elements were applied in the different workshop designs. Ideas for a further modification of the workshop design include the use of costumes, following the approach of Hassan, Harviainen, and Hamari (2018).

For researchers, this study opens new avenues in various directions. First, we have illustrated that the right selection of game elements can indeed foster knowledge retention, and further academic research is needed to identify relevant antecedents and moderators. Second, various gamification principles can be tested to create an incremental research agenda that evaluates the respective contribution of individual game elements on desired cognitive and behavioural outcomes (Liu et al., 2017; Treiblmaier et al., 2018, p. 134). We strongly recommend further longitudinal studies that can test for longer-lasting effects.

7. Conclusion, limitations & further research

In this paper, we investigate whether the use of gamification in educational workshops leads to improved knowledge retention and test for the moderating effect of gender and age We do this using an action research design in which we modify the gamified workshops between iterations to better accommodate students' needs. We compared gamified with non-gamified groups, both of which attended workshops with identical content but different designs. Prior to the workshops, no significant differences were found pertaining to prior knowledge, gender or age. As predicted by previous literature, the level of knowledge recall was highest immediately after the workshops and, despite receding, remained at an elevated level after two weeks in comparison to the knowledge level prior to the workshops. Overall, gamification turned out to have a positive effect on students' knowledge retention, independent of age and gender.

This study has several limitations. We randomly assigned classes, rather than individuals, to the gamified and non-gamified groups, since our pilot study revealed that the division of existing groupings influences student behaviour and produces social threats to the study's validity (Trochim & Donnelly, 2008). The different response rates for our third assessment were influenced by the instructors' willingness to cooperate with us and, although we found no indicators for any underlying systematic bias, we strongly encourage further research to consider a potentially moderating effect of students' motivation on learning outcomes. Furthermore, this study was conducted in Austria and various cultural differences might influence the results (Treiblmaier, Neale, & Chong, 2011). The focus of this study was exclusively on knowledge gains pertaining to memorization skills. Other types of capabilities such as mathematical, language, or social skills were not measured. Also, different learning types, gaming types, or personal characteristics were not controlled for at the individual level. According to Nacke and Deterding (2017) and Sailer et al. (2017), individual game elements should be analysed and not the gamification concept as a whole. Since the experiment was designed using gamified full-day workshops, a close investigation of all individual game elements could not be implemented. Finally, the gender distribution of our sample was not fully balanced, which was caused by the fact that we decided not to split up individual classes in order not to cause confusion among the students. This led to a higher proportion of men in the gamified groups and we suggest that future research achieve a better balance in order to investigate a potentially moderating effect of gender.

Our study reveals multiple opportunities for future research. We treat gamification as a black box, since we only consider the combination of various game elements as input and knowledge retention as the educational output. Future studies may delve deeper and strive to find explanations that are more detailed. A possible approach would be to include and test the effect of gamification on hedonic outcomes as mediating factors (Lowry, Gaskin, Twyman, Hammer, & Roberts, 2013). Additionally, it might be worthwhile to closely investigate the motivational and learning effects over a longer period. Qualitative interviews could be used to get a better understanding of the underlying drivers. Moreover, we did not explicitly include the impact of different learning styles in our study and encourage future researchers to investigate differences between learning styles and gaming types (Buckley & Doyle, 2017) as well as the important mediating role of personal characteristics (Leclercq et al., 2017; Van Roy & Zaman, 2018; Yanuschik, Pakhomova, & Batbold, 2015). Further empirical research is needed to ensure the generalizability of the results and to better understand how knowledge acquisition using gamification differs from traditional learning techniques. The further variation of game elements and the structure of the workshops might be of interest. For example, the use of costumes to create 'living avatars' and investigate the social and learning effects, following the approach of Hassan, Harviainen, and Hamari (2018).

Finally, the positive effects of gamification in education are not only limited to its ability to improve knowledge memorization, but also to enhance social and practical skills such as problem solving, collaboration, and communication. Thus, future research might also have a closer look at how gamification can facilitate social dynamics (Moore-Russo, Wiss, & Grabowski, 2017). A strong theoretical background for gamification research, as is suggested in Treiblmaier et al. (2018), will help to better integrate new research with previous findings and to create an incremental research agenda.

Credit author statement

All authors listed have made an equal substantial, direct and intellectual contribution to the work, and approved it for publication.

Declarations of competing interest

None.

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Appendix

Table A1
Search terms

Database	Boolean phrases
EBSCO:	(TI longitudinal OR SU longitudinal OR AB longitudinal) AND (TI education* OR SU education* OR AB education*) AND (TI gamif* OR SU gamif* OR AB gamif*)
Google Scholar	(intitle:longitudinal OR keyword:longitudinal) AND (intitle:education OR keyword:education) AND (intitle:gamification OR keyword:gamification)
ScienceDirect	longitudinal + education + gamification
IEEE Xplore	longitudinal AND education* AND gamif*
Emerald Insight	(title:longitudinal OR abstract:longitudinal OR keyword:longitudinal) AND (title:education* OR abstract:education* OR keyword:education*) AND (title:gamif* OR abstract:gamif* OR keyword:gamif*)

Table A2
Schedule and game elements of workshop design I and II

Workshop designs I and II				
Non-gamified workshop		Gamified workshop		Game elements
09:45–10:00	Assessment (A1)	09:45–10:00	Assessment (A1)	
10:00–12:00	Traditional lecture	10:00–11:00	Interactive lecture	Time constraint, storytelling
		11:00–11:30	Transport calculation	Time constraint
		11:30–12:00	LEGO simulation game	Storytelling, time constraint
12:00–12:15	Container 'Tetris' quiz	12:00–12:15	Container 'Tetris' quiz	Time constraint
12:15–13:00	Break	12:15–13:00	Break	
13:00–13:30	Transport Calculation	13:00–14:00	Future transport ideas Dragons' Den Award ceremony	Storytelling, time constraint, rewards: price & badges
13:30–14:00	Demonstration of simulation game			
14:00–15:00	Company visits	14:00–15:00	Company visits	
15:00–15:20	Break	15:00–15:20	Break	
15:20–15:45	Assessment (A2)	15:00–15:45	Assessment (A2)	
		Whole day (in each exercise)		Leaderboard, immediate feedback, clear goals, competition & cooperation

Workshop design III		
Gamified workshop		**Game elements**
09:45–10:00	Assessment (A1)	
10:00–11:00	Interactive lecture	Time constraint, storytelling
11:00–11:30	Augmented reality game: Logistify	Time constraint, avatar, points, clear goals, immediate feedback, storytelling
11:30–12:00	LEGO simulation game	Storytelling, time constraint
12:00–12:15	Container 'Tetris' quiz	Time constraint
12:15–13:00	Break	
13:00–14:00	Future transport ideas Award ceremony Dragons' Den	Storytelling, time constraint, rewards: price
14:00–15:00	Company visits	
15:00–15:20	Break	
15:00–15:45	Assessment (A2)	
Whole day (in each exercise)		Leaderboard, immediate feedback, clear goals, competition & cooperation

Table A3
Generic structure of the assessment instrument

	Question	Points (Maximum = 10)
KN1	Multiple choice question (four answers)	no answer = 0 1 = one answer correct 2 = two answers correct 3 = all answers correct incorrect answer minus one point
KN2	Single choice (four answers)	correct = 1 false = 0
KN3	Single choice (four answers)	correct = 1 false = 0
KN4	Single choice (four answers)	correct = 1 false = 0
KN5	Multiple choice (four answers)	no answer = 0 1 = one answer correct 2 = two answers correct 3 = three answers correct 4 = all answers correct incorrect answer minus one point

Appendix A4. Workshop Description

At the beginning of each workshop, the class is divided into small teams of three to five students. Next, they complete the questionnaire for Assessment 1. The workshops start with an interactive lecture introducing the topic of sustainable supply chain management. The topic is explained

with the help of practical examples ("storytelling") and feedback rounds are held to ensure a better understanding. During the lecture, content is queried using quiz questions and points are awarded for correct answers. Extra points are added if a team can explain the correct answer to other teams or if the team is able to quickly find an answer. The teams can follow their score throughout the workshop on a leaderboard. After the interactive lecture, the teams play with the *Logistify* app (a learning app which was developed specifically for these workshops) using a tablet computer (i.e., workshop design 3). *Logistify* enables the participants to learn in a playful way how to choose different means of transport, transport chains and logistics professionals, using augmented reality and gamification functionality to indicate correct, suboptimal or incorrect choices. The points achieved in the game are evaluated and the best teams receive additional points. Next, the playful illustration of the working steps of a trimodal logistics hub with a Lego simulation game takes place (see Fig. 4). The participants receive a quick introduction on how to use the Lego simulation game and each team tries to load containers from one mode of transport to another based on a previous explanation on what is the best transport mode for each type of cargo.

Using a container quiz ('Tetris') the teams have to load containers with pallets correctly in order to achieve the highest possible load factor of the containers. Teams achieving the correct solution receive extra points. After the lunch break, the teams develop future transport ideas using a moderated design thinking process. These ideas are then presented to all teams and evaluated by the other groups as well as external evaluators. The group with the highest daily score receives a prize during an award ceremony. A company visit to local logistics companies takes place afterwards to give the students the opportunity to experience the workshop's content in a real-world environment. At the end of the workshop, all participants complete the questionnaire for Assessment 2.

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