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Article

Influence of gamification on skill-based training of surgical residents

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Abstract

Potentially games increase motivation and thus support the learning process. Gamification effect on different skill levels of surgical residents was limitedly studied. This study aims to better understand the effect of motivation gained through gamification on simulation-based surgical training environments for novice and intermediate surgical residents' performances. An educational scenario with a haptic interface is designed in two versions: gamified and non-gamified. The tasks are performed twice, with the dominant and non-dominant hands resemble the task difficulty. 26 novice and intermediate surgical residents were randomly assigned to one of the groups (gamified or non-gamified). Gamification positively improved novice surgical residents' performances under both hand conditions. However, surprisingly, in some situations, results indicated lower performance by the intermediates compared to the novices. A flow model for this specific scenario is proposed. To benefit the gamification effect, learners' skill levels and content should be carefully assessed and balanced on simulation-based surgical skill training materials.

1. Introduction

Gamification uses game mechanic techniques to create more fun and improve learning through instructional systems. Gamification is defined as the use of game design elements in non-game contexts, which is a reward-based design that provides motivation and an enjoyable environment for users [1]. According to research, using gamification encourages learning by incorporating appropriate game elements, provides game-thinking for solving problems [2], and results in behavior changes and positive outcomes [3] by increasing motivation, reducing anxiety, and supporting physical activity [4]. Hence, those games that entertain players as they educate, train, and challenge are called "serious games" [5]. Foer instance, it is shown that the guided exploratory game-based training improved the students' overall fire evacuation assessment and kept them interested in the suggested learning scenarios [6].

Earlier research shows that serious games can potentially improve the motivation and progress of learners [7], [8] and increase understanding of basic healthcare concepts [9] and knowledge such as in antibiotic prescription [10] for medical students. For instance, by analyzing 115 articles a review study reports that the Wii Fit game environment can be potentially used for rehabilitation purposes in various clinical situations [11]. Earlier research results also reported that children with attention deficit hyperactivity disorder showed improvements in their hyperactivity/impulsivity, oppositional defiance, and focus [12]. Studies report satisfying perceptions of the nursing students on video game based serious games for teaching clinical reasoning and decision-making skills [13]. However, the results of earlier research also indicate the importance of the design of educational environments to create more engaging computer-based learning systems in unsupervised learning situations [14].

It has been reported that there is a need for new approaches to improve surgical education programs [15] and to reassess medical education practices [16]. Accordingly, using simulators in laparoscopy operations for training has been shown to improve surgeons' motor skills while enhancing patient safety [17]. In this respect, virtual simulation environments have the potential to cause a positive change in surgical education programs [18], [19], [20].

As serious games are popular in different educational settings, their potential in medical education could be an interesting investigation. On this concern, there is evidence suggesting that through games and simulations, health professionals' skills, knowledge, and attitudes can be improved [21]. For instance, a short online game reported offering alternative training for health participants in managing aggressive situations when face-to-face training is not possible [22]. Games allow an independent practice other than the operating room through discovery and exploration in an entertaining, engaging, and cost-effective manner [23]. Through serious games, complex decision-making skills, which are vital for medical purposes, can be improved [24]. By reviewing 12 articles, another study reports that video game players acquire non-robotic endoscopic techniques faster and that training with video games improves their performance [25].

Accordingly, several serious games have been developed to this end [26] such as to provide practice for knee replacement surgery procedures [27] and to train blood management in orthopedic surgery [28]. A study reported that playing video games has a major effect on surgical performance in terms of visual performance, eye-hand coordination, reaction time, and controlling motor skills [26]. The authors of another study claim that video games have a positive effect on physicians, resulting in fewer errors during laparoscopy operations [29]. The effect of games on the enhancement of virtual surgical endoscopy skills in medical students was studied experimentally, indicating that video games can improve such surgical skills [30]. Furthermore, some studies in the literature claim that not only health professionals but also individuals' visual attention skills improved with the help of video games [31]. Previous research has also found a link between play and learning [32]. There is evidence showing that gamification has a positive effect on first-year surgical residents in terms of improving their motivation, completing tasks in a shorter period, and motivating them to continue training at later times [33]. Gamification has also been shown to improve their responses to equipment-related problems during surgery [34] and their minimally invasive surgical skills [35]. In another study, it was found that competitive gaming sessions can be used as a primary teaching technique, contributing positively to students' learning and satisfaction [36]. There is also evidence of skill transfer between a serious game and validated laparoscopic simulator technology [37]. Therefore, learning through games is considered an alternative instructional model for surgical education programs [38]. Studies report that using game-like frameworks in anesthesia simulation potentially decrease trainee anxiety [39]. The findings of an earlier study imply that using games to improve surgical team performance abilities seems like a promising training method [40]. However, besides their increasing popularity in education, a need for more insights into the critical design features of simulation games, especially for clinical and cognitive skills, has been also reported [41]. Even though learners' skill levels and characteristics have been reported to be important for game-based learning environments, there has been no study about the gamification effect on different skill levels of learners [42] in general or in endoscopic surgery. Earlier studies also report that to improve the possible benefits of games on medical education, the case complexity and fidelity level, motivation, and skill development need to be further studied [41]. Specifically, no study has been established to understand the gamification effect on two very close skill levels: novice and intermediate-level endoscopic surgery residents. Therefore, the present study aims to shed light on the effect of gamification in simulation-based surgical skill training environments designed for novice and intermediate endo-neurosurgery residents. By better understanding the gamification effect on different skill levels, the benefits of gamification for these different learner groups can be improved, which in turn affects the quality of the surgical education programs.

2. Methods and Material

The endoscopic surgery is conducted through an endoscope through small entrance points to the surgical area. For instance, the endoscopic pituitary surgery is conducted through the nose nostrils. The endoscope has a camera and a light source. The surgeon is required to control the endoscope to see the view of the environment on a monitor and perform the operation through the operational tools controlled by the other hand of the surgeon. Hence, such surgical procedures require development of several skills like depth perception, left-right hand coordination, two dimensional and three dimensional conversions and eye-hand coordination [43]. To gain these skills, they do not have many opportunities for practicing purposes. Usually, their training conducted in the operating room by watching the surgical procedures done by the expert surgeons. They do not have a chance to use and control an endoscope until their final year of five-year training program. To help the surgical residents to develop the necessary skills for endoscopic surgery procedures, a practice scenario is prepared with haptic interfaces. The training scenario is developed in two versions: one with some gamification features and one without any gamification. As the process of controlling the endoscope with very accurate movements is very challenging process for the surgical residents, the tasks in the scenario designed as representative of this challenging process. Additionally, to help the participants to get familiar with the experimental environment, a practice scenario is also developed. Afterward, an experimental study is conducted with surgical residents.

2.1 Participants

There are very limited number of residents in the field of endoscopic surgery. For this reason, it is not always possible to reach many groups for experimental studies. In this study, 26 residents voluntarily participated. All of them were from the neurosurgery and ear, nose, and throat (ENT) surgery departments of a medical school. Table 1 shows the average values of participants' experiences in observing, assisting, or performing an endoscopic surgery in the operating room.

Table 1. Participants

Experience Level	Endoscopic Surgery Experience				Gender		
	Average Observed	Assisted	Performed	Average Age	F	M	Total
Novice	13.11	5.12	0	25.53	3	14	17
Intermediate	61.11	42.00	21.77	28.89	1	8	9
Total					4	22	26

The expertise and skill levels in minimally invasive surgery have been defined for novices as individuals who have just started to acquire the basic knowledge of endoscopic surgery and for intermediates as individuals who have just started endoscopic surgery operations [44]. In this study, these same definitions are used. Accordingly, endoscopic surgery residents who have conducted at least one operation on their own are classified as "intermediate." In contrast, those involved in endoscopic surgery operations but who have not performed any operations on their own are considered "novices."

2.2 Procedure

Table 2 shows that the participants were randomly grouped into two for this experimental study. Accordingly, 12 participants (seven novices and five intermediates) were in the gamified, and 14 participants (ten novices and four intermediates) were in the non-gamified versions of the scenario. This study has been approved by the ethical committee.

Table 2. Experimental Groups

	Novice	Intermediate	Total
Gamified	7	5	12
Non-Gamified	10	4	14
Total	17	9	26

2.2.1 Calibration Process

Participants were first asked to perform a calibration process with the haptic device used in the scenario. In this process, the participant needs to control the arms of the haptic device by pulling in such a way as to synchronize the haptic device with the virtual environment. In case the calibration was not done correctly, the participant was asked to perform the calibration process again.

2.2.2 Practice Scenario

As the simulation environment and the haptic devices were new to the participants, a practice scenario was prepared to familiarize them with the environment. After the calibration process, each participant was asked to perform tasks in a practice scenario to get familiar with the haptic device and the simulation environment. No performance data was collected for the practice scenario.

As endoscopic surgery requires coordination of both hands, skill improvement in both hands for surgical residents is necessary. For this reason, in this study, surgical residents' dominant and non-dominant hand skills were analyzed. Each participant is asked to perform this scenario two times with their dominant hand and non-dominant hand. The experimental study with each participant, including the practice and the training scenarios performed under dominant- and non-dominant hand conditions took approximately 20 minutes for each participant.

2.2.3 Training Scenario

After the practice scenario, the participants were asked to perform the tasks in the training scenario. The training scenario was prepared to provide practice for endoscopic surgical procedures. Accordingly, in this scenario, the participants are required to move a loop attached to a stick through a shaped wire (see Figure 1).

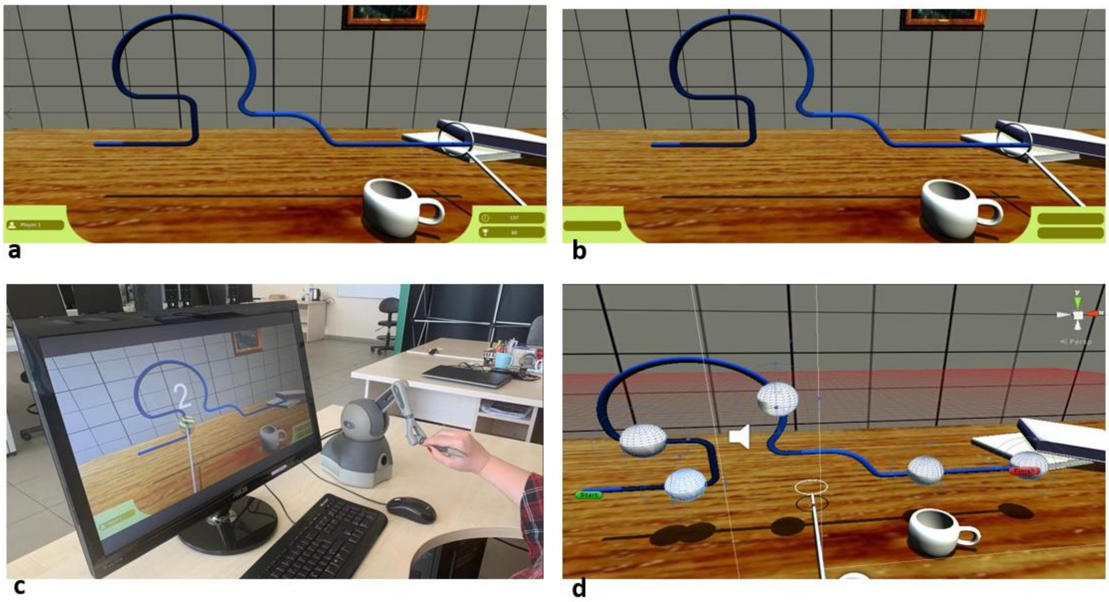

Figure 1. The Training Scenario and Experimental Setup

Each participant starts from the left side of the wire and moves to the right side of the wire, trying not to touch it. If the participant touches the wire at any point, a yellow ball appears on the screen, and the participant must wait for three seconds to give time to reposition the stick and continue the process with a right angle (see Figure 1. c). The wire is divided into five parts, as shown at the five target points in Figure 1.d. Each of these parts is calculated as a task in this scenario. There is a green bar at the bottom of the screen with three boxes. This scenario is prepared in two versions, namely, gamified, and non-gamified. As seen from Figure 1. b, in the non-gamified version, no information is displayed in this green bar section of the scenario. However, in the gamified version, some feedback is provided to the user in this section, as described below.

2.2.4 Gamification

Gamification was introduced to the simulation scenario by showing the score and time for the play. The total time spent during the play of the scenario was shown in seconds in the upper right box of the yellow bar. When the participant reaches any of the targets (see the five target points shown in Figure 1.d), 20 points are added to the score and displayed on the rightmost bottom window of the yellow bar (see Figure 1. a). Other than this score and time information, a general name identifying the participant is also shown at the leftmost window of the yellow bar. Finally, in the gamified version, when the participant touches the wire (when a collision occurs), a sound is heard to warn of the event. On the other hand, for the non-gamified version, these boxes are left empty, as seen in Figure 1. b, and no sound effect appears. Other than this, there is no design difference between the two versions of the training scenario.

2.2.5 Tasks in the Training Scenario

The wire was divided into five parts, as seen in Figure 1.d, and the participants' performance for each of these five parts was recorded separately, representing five tasks. If the participant reaches the target location appropriately in 30 seconds, the task performance for the identified target location is stored as successful, and a value of "1" is assigned for that task. Otherwise, it is considered unsuccessful for this task, and a value of "0" is assigned. This value is the accuracy of the task. Additionally, the duration in seconds that is spent to reach the target location is also recorded for each task. Hence, for each of the five tasks, the simulation software recorded accuracy and duration values automatically.

2.2.6 Measures in the Training Scenario

Accuracy: For each participant, an average accuracy value is calculated by taking the average of the accuracy values of all five tasks.
Duration: For each participant, an average duration value is calculated by taking the average of the duration values of all five tasks.

2.2.7 Execution of the Experiment

Each participant performed the training scenario twice: once with the dominant hand and once with the non-dominant hand, where they had more difficulty performing the task. To eliminate the order effect caused by the hand condition, the first participant performs the tasks under the dominant-hand condition and then the non-dominant-hand condition. The second participant performs the task under the non-dominant hand condition and then, the dominant hand condition to eliminate the order effect. These sequences are balanced in both the scenario's gamified and non-gamified versions. Hence, in each group (game and non-game), half of the participants started the experiment with their dominant hand and the rest with their non-dominant hand.

2.2.8 Research Question

The main research question of this study is:

What is the effect of scenario difficulty level (performing the scenario with the dominant hand or non-dominant hand) and trainees' skill level (novice or intermediate) on their task performance?

3. Results

In this study, a two-way repeated measures ANOVA is conducted to explore the performance differences between the experience levels (intermediate and novice groups) on gamified and non-gamified versions of the training scenario in terms of task completion time (duration) and accuracy. The participants repeated the tasks under both dominant-hand and non-dominant-hand conditions.

Duration: The interaction effects of gamification, experience level, and hand condition were tested using the multivariate criterion of Wilks' Lambda (Λ). The interaction effect is significant at $\Lambda=0.75$, $F(1,22)=7.528$, $p=0.012$. The mean duration and standard error values of each group are given in Table 3.

Table 3. Results for Duration

Condition	Experience Level	Hand	Mean of Duration	Std. Error
Non-Gamified	Novice	Dominant	23.852	2.677
		Non-Dominant	22.530	2.041
	Intermediate	Dominant	24.624	4.233
		Non-Dominant	31.157	3.227
Gamified	Novice	Dominant	21.206	3.200
		Non-Dominant	24.411	2.439
	Intermediate	Dominant	30.074	3.786
		Non-Dominant	18.390	2.886

Accuracy: The interaction effects of gamification, experience level, and hand condition were tested using the multivariate criterion of Wilks' Lambda (Λ). The interaction effect is significant at Λ=0.72, F(1,22)=8.627, p=0.008. The mean accuracy and standard error values of each group are given in Table 4.

Table 4. Results for Accuracy

Condition	Experience Level	Hand	Mean of Accuracy	Std. Error
Non-Gamified	Novice	Dominant	.760	.084
		Non-Dominant	.820	.079
	Intermediate	Dominant	.700	.133
		Non-Dominant	.500	.125
Gamified	Novice	Dominant	.914	.101
		Non-Dominant	.686	.095
	Intermediate	Dominant	.640	.119
		Non-Dominant	.960	.112

4. Discussion

The results of this study indicate that, under the gamification condition, the novice participants performed the tasks in a shorter time (e.g., Duration = 21.206) with better performance (e.g., Accuracy = 0.914) when they were performing the tasks with their dominant hands compared to their non-dominant hands (e.g., Duration = 24.411, Accuracy = 0.686). This is an expected result because the dominant hand's skills are better than the non-dominant hand's. For instance, an earlier study reports that the force production variability of the non-dominant hand requires more corrections and movement time compared to the dominant hand [45]. Hence, when they performed the tasks with their dominant hand, gamification positively affected them. On the other hand, surprisingly, the intermediate residents' performance is worse under the game condition when they perform the tasks with their dominant hand (accuracy = 0.640, duration = 30.074) compared to the non-dominant hand condition (accuracy = 0.960, duration = 18.390). This can be considered an interesting and contradictory result of the study.

The current study's findings can only be explained by the flow theory. Earlier studies report that the balance between challenge and learning in serious games needs to be built in such a way that the learner is challenged to keep on playing and to reach the game's objective [46] . For instance, according to a study, fidelity level and complexity are important factors that need to be considered when creating a challenge in serious games for clinical cognitive skills [41]. An earlier review study also reports the heterogeneous results of studies about the flow experience by also reporting the possibility of the associations between cognitive and experiential aspects of flow which is defined as a positive mental state characterized by heightened arousal, focused attention, synchronized activity in the brain's attention and reward networks and results in automatic action control with less self-referential processing [47]. Besides being in flow is reported as maximizing the students' learning potential in problem solving environments [48].

According to the results of another study, a high-fidelity simulation game increased complexity but did not improve the novices' skill levels [41]. The researchers have reported that, to create effective cognitive skill training, the complexity and fidelity of cases should be aligned with students' proficiency levels, and more design-based research is needed on the relationship between case fidelity, motivation, and skill development for novices and experts [41]. Studies also report that, based on different design perspectives, the level of involvement and skill improvements may vary [49] and that the current skill levels of players are closely related to the challenge in the game. According to an earlier study [50], if the difficulty level of the content is not in parallel with the skill levels of the players, they will remain outside of the flow and, as a result, the expected benefits from a game-based learning environment cannot be reached. According to Csikszentmihalyi, the right level of difficulty for challenges in learning materials is critical for optimal learning gain. This absorbed state is named the zone of flow [51]. According to him, flow occurs when an individual's skills match the challenge, whereas when his or her skill levels are higher than the challenge, it will result in boredom. If demands outweigh skills, it will result in anxiety. In other words, an individual in flow performs tasks at full capacity [52]. To put these people into the flow, a balance needs to be established between their perceived action capacities and skills [53]. If the skill levels exceed the level of challenge, one becomes bored; if the challenges exceed skill levels, the individual becomes anxious [54].

Hence, our results can be interpreted through the flow theory shown in Figure 2. Accordingly, the participants' behaviors, showing a better performance with the flow but a lower performance with boredom and anxiety, are compatible with the theoretical framework of flow theory [51]. These results are also supporting the flow framework in educational games [55]. In parallel with this framework, in this study, majority of the parameters like context, goals, pedagogy, learning objectives were the same for all participants. However, learner characteristics by considering their skill levels were different as novice and intermediate learner groups. This caused differences in their learning experiences on different training scenarios and the flow experience of the learners.

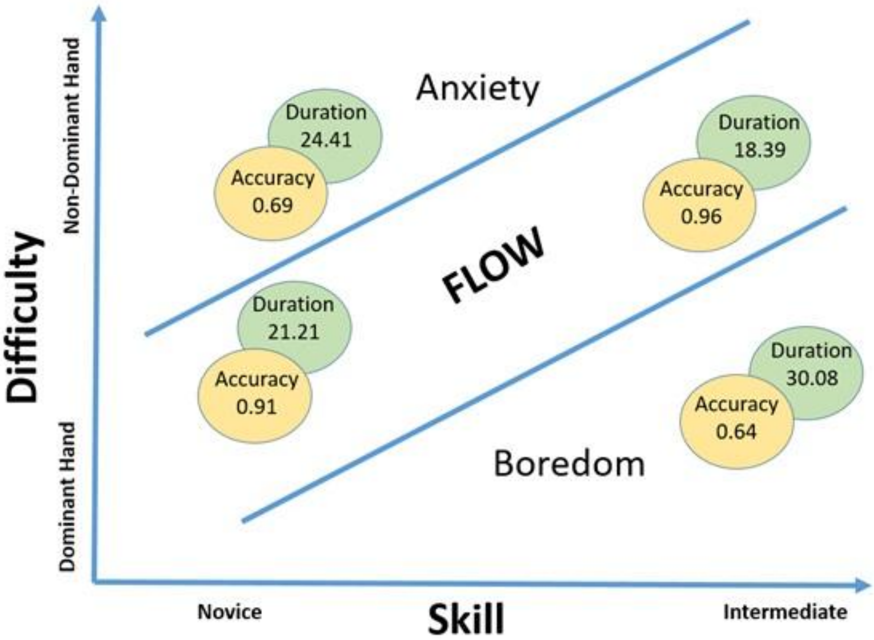

Figure 2. Flow Model of the training scenario

When performing the tasks in the scenario with their dominant hand, since the task has a lower level of challenge compared to their skill levels, the intermediate surgical residents fall into the boredom zone and show a lower performance. However, when they performed the task with their non-dominant hand, the challenge was in line with their skill levels, and they fell into the flow and showed a better performance. These results confirm the results of an earlier study analyzing the self-regulation effect on flow [56]. Self-reaction, a human behavior that involves assessing one's level of satisfaction regularly, has been identified as a constant influencing factor in the flow state [56]. In that study, self-judgment was measured through skill- and game-level difficulty in different states [56]. Additionally, earlier results also show that physicians with high undertriage before enrollment significantly improved with game-based training compare to the ones having with low preexisting undertriage [57]. Because of the nature of endoscopic surgery education, different skill levels of surgical residents were involved in this current study. Additionally, the educational environment is created by involving the dominant and non-dominant hand skills, creating a level of difficulty for performing the tasks in the scenario. Accordingly, the skill levels of the participants and the difficulty levels of the scenarios were objectively measured and considered in the analyses, which are defined under the "self-reaction parameter" by an earlier study [56]. In the future, a flow AI [58] can be adapted to such learning environments to keep the learners in the flow by considering their skill levels and the difficulty levels of the scenarios.

5. Conclusions

According to a review results [59], there is strong empirical evidence about the significance of flow in serious games, although there are mostly conceptual considerations regarding flow in these contexts. They contend that studies on flow have to concentrate on particular facets associated with the essence of serious games that blend entertainment and education [59]. Accordingly, this study shows a specific example for the implementation of flow theory on a specific case. Despite evidence showing that gamification positively affects learning performance, the difficulty level of the content that is aimed to be presented through gamification should be critically evaluated to fit the skill levels of the learners. The results suggest that gamification should be carefully applied by considering the challenges in the content and context in parallel with the skill levels of surgical residents. Hence, as reported by [43], the balance between perceived action capacities and skills needs to be assessed carefully, and skill-based surgical simulation tools must be designed, developed, and used accordingly. In other words, a flow model should be developed by considering the context, content, and skill levels for each scenario to provide game-based learning for surgical training. In turn, such training needs to be offered by considering the flow model. The results also indicate that training modules designed with gamification for different skill-level trainees should be prepared adaptively to fit the display of the content and implementation of gamification according to the skill levels of the trainees.

As there are a very limited number of residents in the surgical education programs, the number of participants in this study is low. When possible, the study can be conducted with larger sets of participant groups with different surgical skill levels. Additionally, the flow experience of the participants, their anxiety levels and boredom levels can also be measured and evaluated to better understand and show the flow effect on the skill-based tasks conducted by endoscopic surgery residents. Based on these results, some adaptive educational content can be prepared for the surgical training programs. For instance, by automatically detecting the skill levels of the surgeons, the gamification approach can be applied to different training scenarios. By continuously analyzing the skill levels and their flow measures, the content can be adapted according to the learners' skill levels and flow behaviors which possible would improve their performance and skill improvements in such training programs.

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Conflicts of interest

The authors declare that there are no conflicts of interest.

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