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Designing and evaluating the effectiveness of a serious game for safe administration of blood transfusion: A randomized controlled trial

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ABSTRACT

Background: Preparing nursing students for the knowledge and skills required for the administration and monitoring of blood components is crucial for entry into clinical practice. Serious games create opportunities to develop this competency, which can be used as a self-directed learning strategy to complement existing didactic learning and simulation-based strategies.

Aim: To describe the development and evaluation of a serious game to improve nursing students' knowledge, confidence, and performance in blood transfusion.

Method: An experiential gaming model was applied to guide the design of the serious game environment. A clustered, randomized controlled trial was conducted with 103 second-year undergraduate nursing students who were randomized into control or experimental groups. After a baseline evaluation of the participants' knowledge and confidence on blood transfusion procedure, the experimental group undertook a blood transfusion serious game and completed a questionnaire to evaluate their learning experience. All participants' clinical performances were evaluated in a simulated environment.

Results: The post-test knowledge and confidence mean scores of the experimental group improved significantly ($p < 0.001$) after the serious game intervention compared to pre-test mean scores and to post-test mean scores of the control group ($p < 0.001$). However, no significance difference ($p = 0.11$) was found between the experimental and control groups on the post-test performance mean scores. The participants evaluated the serious game positively.

Conclusion: The study provided evidence on the effectiveness of a serious game in improving the knowledge and confidence of nursing students on blood transfusion practice. The features of this serious game could be further developed to incorporate additional scenarios with repetitive exercises and feedback to enhance the impact on clinical performance. Given the flexibility, practicality, and scalability of such a game, they can serve as a promising approach to optimize learning when blended with high-fidelity simulation.

1. Introduction

Human error in the administration of blood product leading to adverse events was recognized as the highest risk of transfusion error which can be preventable (Serious Hazards for Transfusion, 2013; Smith et al., 2010). There has been an increased responsibility for nurses to perform this procedure, in which two registered nurses are required to conduct various levels of checks before administration of the blood product (Royal College of Nursing, 2004). Besides safe administration of the blood product, nurses must know how to recognize and manage adverse transfusion reaction. The deficiencies in nurses' knowledge and skills were reported as barriers for safe practice of blood transfusion (Hijji et al., 2013; Serious Hazards for Transfusion, 2013). Nurses were found to be non-compliant with the national standards of blood transfusion, including suboptimal vital sign monitoring and documentation deficiencies (Rowe and Doughty, 2000; Hijji et al., 2013). Education and training are therefore essential to ensure blood transfusion safety.

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A review of the nursing literature identified an increasing number of studies that examined the use of innovative learning strategies to improve nursing students' competency in blood transfusion. The blended learning strategies using didactic approaches followed by simulation learning were examined by several studies (Flood and Higbie, 2015; Prentice and O'Rourke, 2013; Smith et al., 2010). The incorporation of simulation into didactic learning enabled students to apply the theory that they learned through practice in the simulation scenario (Smith et al., 2010). A quasi-experimental study conducted by Flood and Higbie (2015) revealed that students who received a didactic lecture preceding the simulation learning have a better acquisition of knowledge than those who received only the simulation learning. Although this blended learning approach yielded immediate knowledge improvement for blood transfusion safety, this improvement was not sustained over time (Mole et al., 2007; Prentice and O'Rourke, 2013). A study conducted by Smith et al. reported a clear degradation of knowledge six months after the educational programme, which may result in adverse events in transfusion practice. Although the existing studies did not measure clinical performance as a learning outcome, regular reinforcement of learning is recommended to optimize the retention and transfer of learning.

The benefits of simulation in enhancing blood transfusion practice may be optimized through repetitive training, but with significant resource challenges (Al-Ghareeb and Cooper, 2016). Expensive faculty time, the availability of simulation facilities, and scheduling issues are major challenges faced when implementing this resource-intensive modality (Miller and Bull, 2013). For this reason, the use of serious game is taking on a greater role in healthcare education. Serious game, which encompasses the component of simulation, is gaining attention in healthcare education to support the development of knowledge and skills (Wang et al., 2016). A serious game is defined as an interactive computer application, with or without significant hardware component, that has a challenging goal, is fun to play and engaging, incorporates some scoring mechanism, and supplies the user with skills, knowledge, or attitudes that are useful in reality (Bergeron, 2006). According to Killi and Lainema (2008), where game elements are involved in simulation, learning occurs as a result of being focused in a goal directed activity. Serious games and hands-on simulation have similar key features, including the use of a synthetic world structured by rules, feedback mechanisms, and challenges to guide learners in developing competencies (Aldrich, 2009). These strategies should be used as complementary learning tools to optimize clinical competency gain (Cook et al., 2012).

Serious games are emerging as a new pedagogical approach in nursing education. The PUSLE (Platform for Undergraduate Life Support Education) is an example of a game developed for nurses to enhance and maintain life support skills. A randomized controlled trial (RCT) study on 34 nurses demonstrated the effectiveness of the PULSE in improving nurses' key resuscitation skill sets during life support training. In addition, the game was positively evaluated as a learning tool to complement traditional life support training (Cook et al., 2012). While the PULSE was targeted to support Intermediate Life Support (ILS) training (Cook et al., 2012), Life Support Simulation Activities (LISSA) was developed as a serious game to focus on Basic Life Support (BLS) (Boada et al., 2015). A RCT study conducted by Boada et al. (2015) revealed that students who received LISSA performed better in laboratory sessions than students who engaged in reading of the theory material. Although a systematic review conducted from 2007 to 2014 has identified 42 serious games in training health care professionals (Wang et al., 2016), there were only three serious games articles related to nursing education (Blake and Goodman, 1999; Hahn and Bartel, 2014; Cook et al., 2012). Thus, the application of serious games in nursing education is still in its infancy. More works need to be done for development and evaluation to continue the growth of serious game in training healthcare professionals (Wang et al., 2016).

All nurses upon graduation are expected to have the ability to administer blood product safely and monitor for potential adverse reactions. Nurse educators must ensure that student nurses are equipped with the skills and knowledge to perform the procedure. To enhance existing learning strategies, a serious game on blood transfusion was developed as a self-directed learning strategy to complement the high-fidelity simulation. It could be used as a preparatory course prior to their simulation experience as well as a refresher course to maintain their competence after the hands-on simulation. To our knowledge, no serious game on blood transfusion has been developed for nursing education. Therefore, the aim of this study is to describe the development and evaluation of a serious game for developing nursing students' knowledge, confidence, and performance on safe blood transfusion practice.

2. Methods

2.1. Serious Game Design and Development

The serious game was created using a game design platform known as 3DHive by a team comprised of an undergraduate student, a faculty educator, a researcher, and a game developer. The experiential gaming model developed by Kiili (2005) was applied to guide the design of the game environment. The flow elements proposed by the model, which include *clear goals, frame story, challenges, focus attention, playability, gamefulness, feedback, and a sense of control,* were applied in this serious game to optimize game-based learning.

The game is designed to enable players to go through the process of checking and administering blood to a patient who requires it. The *game goal* is to enable its players to experience and understand the blood transfusion procedure. To achieve this, the players are required to go through three stages: pre-transfusion, during transfusion, and post-transfusion. Specific learning objectives were identified for each stage. The players are required to achieve the learning objectives in each stage before moving on to the next stage. An adult female patient with anemia who was admitted to hospital for blood transfusion was used as a *frame story* to situate the learning in a meaningful context. As shown in Fig. 1, the player performs the role of a staff nurse in a virtual hospital ward to undertake the tasks of preparing the patient to receive blood transfusion, administering the blood product safely to the patient, and providing appropriate nursing interventions to manage the patient with transfusion reaction.

Multiple mini games *challenges* were developed from the learning objectives to test the player's knowledge and problem-solving skills. These were developed based on the theory and practical learning contents acquired by the second year nursing students from their prior learning. The level of challenge was therefore adjusted according to the learners' abilities. The mini games were related to specific tasks to keep the player's *attention in focusing* on the task at hand. Some examples include choosing the appropriate equipment to proceed with the blood transfusion and checking the correct blood product using the appropriate documents. The players must provide correct answers in the mini games before they were allowed to move on to the next stage. A scoring system and time challenges were incorporated into some of the mini games to enhance its *gamefulness*. Artificial avatars including a nurse clinician, a doctor, a staff nurses, and a student nurse were also included to enhance the interactivity and engagement of the game, thereby promoting the game's *playability*. Immediate *feedback* on a player's action was provided after each mini game. For example, in a mini game on reporting of transfusion reaction, feedback on the proper structure of communication to the doctor was included. To augment the players' *sense of control*, features including free navigation around the virtual ward and opportunities to redo the mini games were included. The entire game takes about 30 min and the player can only participate once.

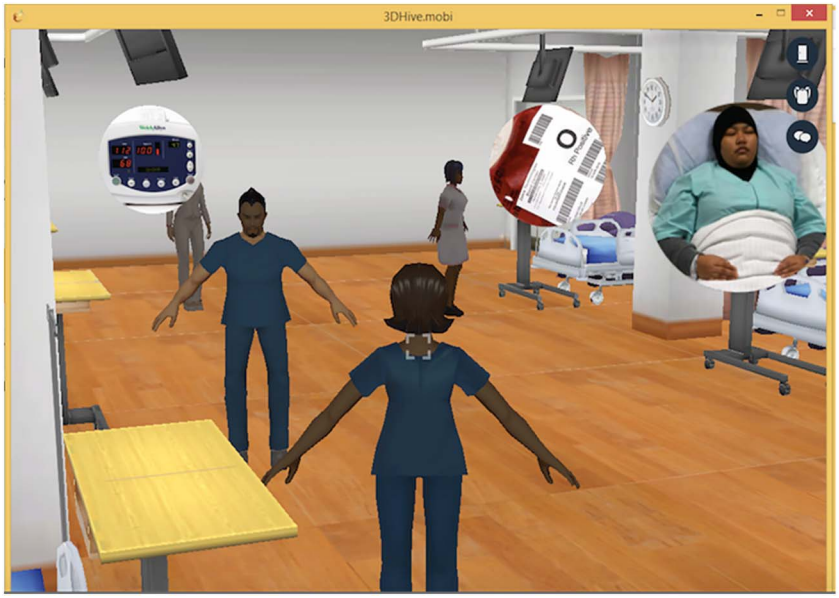

Fig. 1. Virtual hospital ward.

2.2. Serious Game Implementation and Evaluation

2.2.1. Study Designs & Participants

A clustered randomized control trial with a wait-list control group was conducted in a computer laboratory at the National University of Singapore from October 2015 to November 2015. The serious game was implemented in a medical-surgical module of a Bachelor of Science (Nursing) program, The module was undertaken by the second-year nursing students who were divided into seven tutorial groups to undertake the module learning. Using the clustered sampling method, the tutorial groups were randomly assigned to either the experimental ($n = 4$) or control groups ($n = 3$) by drawing pieces of paper indicated with tutorial groupings from a table. The students recruited in each tutorial group were considered as clusters. This sampling method has the potential to minimise intervention "contamination" between the experimental and control groups participants (David, 2001). All students from the seven tutorial groups were approached to participate in the study after receiving approval from an institutional review board. While students from the experimental tutorial groups undertook the serious game as a part of the study intervention, students from the control tutorial groups were wait-listed to receive the serious game learning after the research study. Based on the effect size calculated from a previous study, a sample of 16 participants per tutorial group was considered to be sufficient for achieving 80% power at the 5% alpha level (van Breukelen and Candel, 2012).

2.2.2. Procedure

Fig. 2 illustrates the flow of the study procedure. Both control and experimental groups received an equal amount of lectures and skills laboratory lessons on blood transfusion prior to data collection. Demographic, knowledge, and confidence surveys on blood transfusion were administered to all participants. About two weeks after the pre-tests, the participants in the experimental group undertook the serious game intervention and completed the post-test knowledge, confidence, and perception questionnaires immediately after the intervention. The post-test knowledge and confidence questionnaires were also completed by the participants in the control group on the same week. The participants from both groups were scheduled to undertake the performance post-test individually at the university's simulation laboratory about two weeks after the study intervention. During the simulation-based assessment, each participant was presented with a clinical scenario, role played by a simulated patient, of an elderly patient with chronic illness and anemia who required blood transfusion. They were tasked to perform a safe administration of blood product and respond to transfusion reaction. The entire simulation performances were assessed by eight faculty nursing educators who were blinded to the participants' group allocation. The simulation process was recorded on video and viewed by two independent assessors to establish the inter-related reliability.

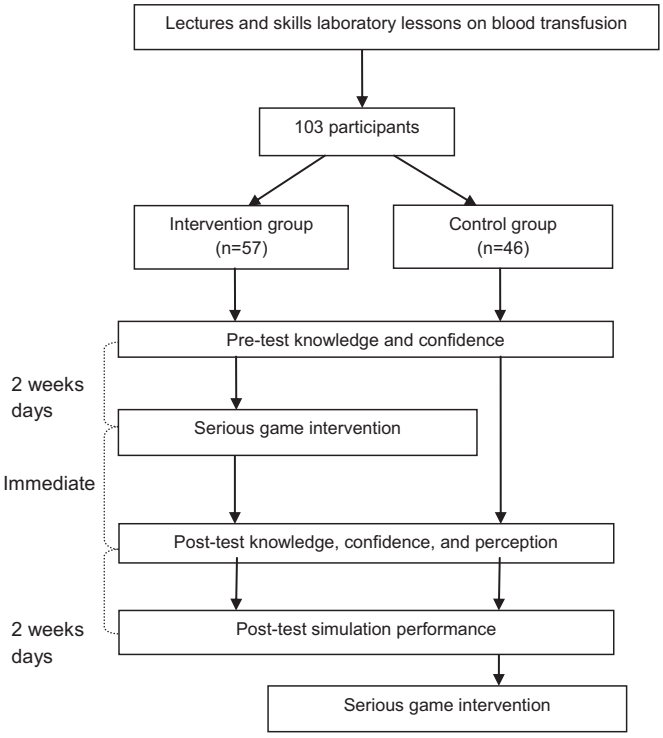

Fig. 2. Flow of study procedure.

2.2.3. Instruments

2.2.3.1. Knowledge Questionnaire. The 20-item multiple-choice questionnaire was developed by the research team to evaluate the participants' knowledge on blood transfusion. Content validity of the questionnaire was established by a panel of five nursing experts.

2.2.3.2. Confidence Scale. A 5-item confidence scale with a 10-point scale, developed by Grundy (1993), was adopted to measure the confidence level of the participants in performing the blood transfusion procedure. The scale showed a high internal consistency of 0.96 for Cronbach's alpha in this study.

2.2.3.3. Performance Tool. A 25-item performance tool with a combination of checklist items (2-point scale: 0 = not performed; 1 = performed) and a global rating scale (10-point scale) was developed by the research team to assess the students' performances in safe administration of the blood product and in responding to transfusion reaction. The tool was validated by a panel of seven nursing experts. The inter-rater reliability was tested across two raters who scored 15 video-recorded simulation performances independently. A moderate intraclass correlation coefficient of 0.79 (confidence interval of 95%) was found for the tool.

2.2.3.4. Perception Scale. A 16-item game perception scale developed by Huang et al. (2013) was adopted to evaluate the participants' perceptions of the serious game. The scale consists of five subscales (immersion, interaction, imagination, motivation, and enhanced problem solving capacity) (Huang et al., 2013). The scale was found to have a high internal consistency ($\alpha = 0.94$) with a Cronbach's alpha of ($\alpha = 0.97$) in this study.

2.3. Data Analysis

Demographic variables and game perception scores were computed using descriptive statistics. Any significant changes between pre-test and post-test scores were evaluated by paired *t*-tests. Between-group comparison of post-test scores was performed using independent *t*-tests and ANCOVA, using pre-test scores as covariance. Correlation of study variables was tested using Pearson's correlation coefficient test. Inter-rated reliability was computed using intra-class correlation coefficient.

3. Result

3.1. Demographic Data

One hundred and eleven participants were recruited, with 62 participants allocated to the experimental group and 49 participants allocated to the control group. However, only 57 participants in the experimental group and 46 participants in the control group completed the study. As shown in Table 1, the average age of the participants was 20.95 years old. Most were female (86.4%) and Chinese (81.6%). There was no significant difference in characteristics between the experiment and control groups, including gender ($p = 0.20$), age ($p = 0.21$), ethnicity ($p = 0.13$), and the number of nursing diploma holders ($p = 0.83$). This finding indicated the homogeneity of the participants between the two groups.

Table 1
Demographic characteristics.

Characteristics		Experiment group *N* (%)/M (SD)	Control group *N* (%)/M (SD)	$\times^2$	*p*
Age		21.14 ± 2.08	20.72 ± 0.96	19.3	0.21
Gender					
	Male	10 (17.5%)	4(8.7%)	1.70	0.20
	Female	47 (82.5%)	42 (91.3%)		
Ethnicity					
	Chinese	45 (78.9%)	39 (84.8%)	0.576	0.13
	Malay, Indian, and Others	12 (21.1%)	7 (15.2%)		
Holds nursing diploma		9 (15.8%)	8 (17.4%)	0.047	0.83

3.2. Knowledge Scores

As shown in Fig. 3, no significant difference ($t = -1.25$, $p = 0.21$) was found between the experimental (M = 11.39, SD = 2.23) and control groups (M = 11.76, SD = 2.26) in the knowledge pre-test mean scores. After the intervention, there was significant improvement in the pre-test (M = 12.02, SD = 2.74) and post-test (M = 16.46, SD = 1.86) mean scores within the experimental group ($t = -10.73$, $p < 0.001$). No significant difference ($t = -1.05$, $p = 0.30$) between the pre-test (M = 11.39, SD = 2.23) and post-test (M = 11.76, SD = 2.26) mean scores was found within the control group. Between-group comparison using ANCOVA indicated that the experimental group (M = 16.46, SD = 1.86) had significantly higher post-test mean scores ($F = -11.46$, $p < 0.001$) than the control group (M = 11.76, SD = 2.26).

3.3. Confidence Scores

As presented in Fig. 3, there was no significant difference ($t = 0.66$, $p = 0.51$) in the baseline confidence mean scores between the experimental and control groups. The experimental group demonstrated a significant increase ($t = -9.49$, $p < 0.001$) in the post-test confidence mean scores (M = 31.56, SD = 8.77) from the pre-intervention scores (M = 20.8, SD = 9.75). The control group demonstrated no significant improvement ($t = 0.25$, $p = 0.803$) of pre-test confidence mean scores (M = 19.61, SD = 8.48) from the post-test confidence mean scores (M = 19.39, SD = 7.57). Between-group comparisons using ANCOVA demonstrated significantly higher post-test confidence mean scores ($F = -9.04$, $p < 0.001$) in the experimental group (M = 31.56, SD = 8.77) than the control group (M = 19.39, SD = 7.57).

3.4. Simulation Performance Scores

Based on the simulation-based assessment, the experimental group demonstrated a higher performance mean scores (M = 24.91, SD = 5.04) than the control group (M = 22.89, SD = 5.14). However, no significant difference ($t = 1.64$, $p = 0.105$) was found in the performance mean scores between the two groups.

3.5. Perception Scores

As shown in Table 2, the overall mean scores of 5.20 (SD = 0.30) from a 16-item survey with a 7-point Likert-scale showed that the participants generally hold positive attitudes towards the serious game. The highest mean score item (M = 5.63, SD = 1.16) was “I feel the serious game improves my understanding of the blood transfusion procedure” and the lowest mean score item (M = 4.53, SD = 1.60) was “I feel immersed in the serious game environment”.

3.6. Correlation between Study Variables

There were significantly weak to moderate positive correlations between knowledge and confidence mean scores ($r = 0.55$, $p < 0.001$), confidence and performance mean scores ($r = 0.30$, $p < 0.001$), and knowledge and performance mean scores ($r = 0.25$, $p = 0.01$).

4. Discussion

The lack of knowledge has been identified as one of the barriers of safe practice for blood transfusion (Parris and Grant-Casey, 2007). In this study, the pre-test knowledge scores conducted three weeks after a

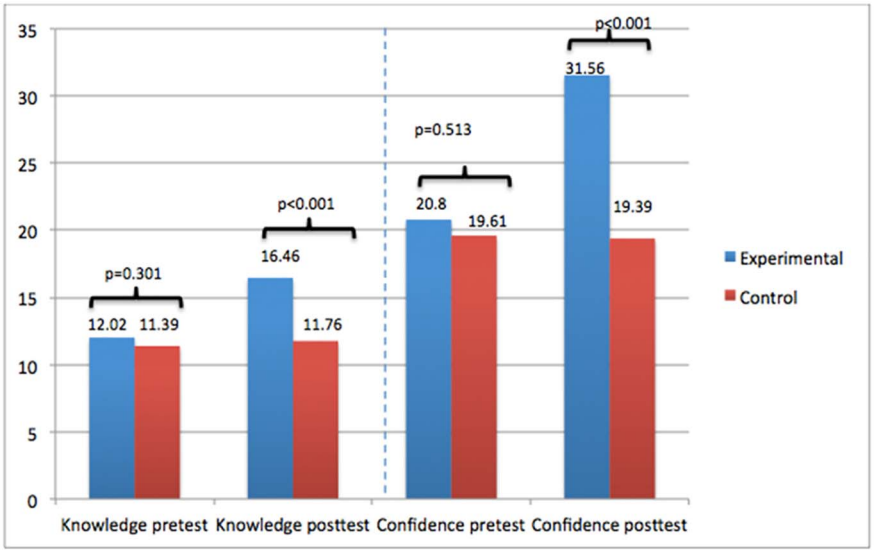

Fig. 3. Pre-tests and post-test mean scores on knowledge and confidence.

Table 2
Scores on learners' perception towards the serious game.

Items	Mean (SD)
Overall	5.20 (± 0.30)
Subscale: Immersion	4.79 (± 0.26)
The serious game has a realistic-looking learning environment	4.80 (± 1.18)
I pay more attention when using the serious game	5.05 (± 1.33)
I feel immersed in the serious game environment	4.53 (± 1.60)
Subscale: Interaction	4.94 (± 0.21)
I would like to share my serious game learning experience with other learners	4.79 (± 1.44)
The serious game can enhance teacher–learner interaction	4.86 (± 1.75)
The serious game can enhance learner–learner interaction	5.18 (± 1.38)
Subscale: Imagination	5.59 (± 0.05)
The serious game gives me more engagement to help me understand the learning content	5.53 (± 1.21)
I feel that the serious game improves my understanding of the blood transfusion procedure	5.63 (± 1.16)
I feel that the serious game helps me better understand how to manage a blood transfusion reaction	5.61 (± 1.05)
Subscale: Motivation	5.20 (± 0.09)
It is impressive using the serious game for learning purposes	5.18(± 1.40)
The serious game can enhance my learning interest	5.30 (± 1.41)
The serious game can enhance my learning motivation	5.12 (± 1.45)
Subscale: Enhanced problem-solving capacity	5.21 (± 0.08)
The serious game can enhance my learning capability	5.19 (± 1.53)
The serious game can enhance my problem-solving capability	5.10 (± 1.49)
The system can enhance my capability of knowledge construction	5.26 (± 1.31)
The system can enhance my capability of knowledge management	5.28 (± 1.33)

lecture on blood transfusion indicated that there is still much room for the participants to improve their knowledge. This finding also suggested that didactic learning may not be sufficient for acquiring of knowledge on blood transfusion. The finding therefore supports previous studies (Flood and Higbie, 2015; Hogg et al., 2006) on the need to explore other learning modalities that could support the learning of blood transfusion to ensure safe administration of the blood product.

In this randomized controlled study, we demonstrated the effectiveness of a serious game in improving nurses' knowledge on blood transfusion. This finding is consistent with the participants' evaluation of the serious game in improving their understanding of the blood transfusion procedure. The use of a serious game in improving the acquisition of knowledge in nursing practice has been supported by previous studies (Boada et al., 2015; Lancaster, 2014). In congruent to a study by Kosmadoudi et al. (2013), we applied the concepts of mastery learning to the design of the game's learning content to promote acquisition of knowledge. The learning content was divided into smaller units, comprised of three stages of blood transfusion, with specific learning objectives set for each unit. The learners engaged the learning in a logical sequence through a series of mini games. Each mini game, which took about a few minutes to complete, was generated from a specific objective. These mini games tested its players across the different levels of Bloom's taxonomy including knowledge, comprehension, and application. Immediate feedback, which is crucial in guiding the player to learn, was provided after each mini game. Throughout the game, the player is required to complete all learning objectives in each unit before progressing to the next stage. As our study provided positive outcome on knowledge acquisition, we called upon a game designer and an educator to integrate the concepts of mastery learning into game-based learning.

Given that the experimental group has acquired higher levels of knowledge, it is unsurprising that this group demonstrated increased confidence levels in performing the blood transfusion procedure after the gaming intervention. This finding is consistent with the result of previous studies where the participant perceived having better abilities to translate the tasks to simulation or actual clinical setting after engaging the game (Bogossian et al., 2015; Lancaster, 2014). A moderate positive correlation between the knowledge and confidence scores was also reported in this study. However, a weaker positive correlation was found between the knowledge and performance scores, and between the confidence and performance scores. A possible explanation could be that the data collection for the level knowledge and confidence was evaluated immediately after the study intervention, whereas the performance test was conducted two weeks after the intervention. A decay of knowledge may have occurred over time that affected the performance. This may suggest the need to undertake the serious game on a regular basis to ensure learning retention.

With the improvement of knowledge, we would expect the participants in the experimental group to demonstrate a better performance through their abilities to apply clinical reasoning skills. However, although the experimental group did demonstrate a higher level of performance than the control group, it was not statistically significant. This finding contradicted previous studies on serious game that demonstrated a significant improvement in the learners' performance (Creutzfeldt et al., 2012; Boada et al., 2015). As our serious game only incorporated a single scenario, the lack of practice with multiple

scenarios and feedback could have resulted in a less favorable outcome on our participants' performance. A systematic review on instructional design in internet-based learning identified the incorporation of features including interactivity, practice exercise, repetition, and feedback to influence positive learning outcomes. A study by Liaw et al. (2014) that incorporated these features in an internet-based learning demonstrated a similar outcome as the high-fidelity simulation learning in improving clinical performance. The further development of the serious game should incorporate more scenarios with repetitive exercise and feedback in order to achieve a positive impact on clinical performance. However, it is noteworthy that serious game cannot be used as a substitute for high-fidelity simulation (Cook et al., 2012). The performance of blood transfusion requires procedural skills which cannot be gain optimally in a serious game. The development of procedural skills will clearly require simulation that provides hands-on kinesthetic learning in a realistic situation. Both serious game and hands-on simulation should be used as a blended-learning strategy to optimize clinical performance of blood transfusion.

The participants reported positively on their evaluation of the serious game. They valued the game in enhancing their motivation to learn and understand the learning contents, and improve their problem-solving capacity. Drawing on the experiential gaming model, we incorporated features including clear goals, frame story, challenges, focus attention, playability, gamefulness, feedback, and a sense of control into the serious game. The integration of pedagogy and game design was emphasized in the model to ensure the construction of knowledge and engagement of learning at the same time (Kiili, 2005). The lowest rating for immersion suggested that the serious game may not be sufficiently realistic for allowing participants to feel immersed in the game. The realism of a learning environment that closely matches to a real-world setting is important to facilitate the transfer of learning (Huang et al., 2013; Robinson and Dearmon, 2013). The virtual world image of the hospital ward in the serious game can be better enhanced by adding more audiovisual effects or being constructed using three-dimension imaging technology.

There are few limitations that warrant attention. First, although an RCT was used to evaluate the effectiveness of the serious game, the quality of the evidence could be limited by the no-intervention control group. A comparison of the serious game with other combined strategy, such as serious game and high-fidelity simulation, could be conducted in future studies to test the effectiveness of a serious game as a part of a blended-learning approach. Second, as a result of the faculty's and students' time constraints, the outcome measures were limited to immediate and two weeks after the study intervention. A future study could measure the long-term retention of learning. Third, due to a lack of specific tool to measure critical thinking skills, the measurement of learning outcomes was limited to knowledge, confidence, and performance in this study. There is a need for a future study to develop a specific tool to measure the application of critical thinking for practice (Carter et al., 2015). Lastly, despite of the good inter-rater reliability score reported by the performance tool, the numerous assessors involved during the simulation may have resulted in a variation of assessment standards.

5. Conclusion

This study provided evidences on potential of gaming technologies in engaging students' learning and developing their knowledge and confidence on safe blood transfusion practice. The findings have encouraged us to continue developing the serious game to realize its full potential. Given the flexibility, practicality, and scalability, it serves as a promising pedagogical approach to optimize learning when blended with high-fidelity simulation.

Conflict of Interest

No conflict of interest has been declared by the authors.

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