



Now I know how! The learning process of medication administration among nursing students with non-immersive desktop virtual reality simulation



Ilana Dubovi ^{a, b, *}, Sharona T. Levy ^a, Efrat Dagan ^b

^a Department of Learning, Instruction and Teacher Education, Faculty of Education, University of Haifa, Israel

^b The Cheryl Spencer Department of Nursing, Faculty of Social Welfare and Health Sciences, University of Haifa, Israel

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ABSTRACT

The purpose of this study was to create and explore an effective and accessible teaching method for the higher education of professionals requiring practical skills. We aimed to evaluate the effectiveness of our Pharmacology Inter-Leaved Learning Virtual Reality (PILL-VR) simulation when applied to nursing education, as a tool for learning medication administration procedures. A quasi-experimental pretest-intervention-posttest comparison group design was conducted based on quantitative analysis of questionnaires, video recordings and worksheets. Participants were nursing students who either learned medication administration processes with a PILL-VR simulation platform (experimental group; $n = 82$) or who learned with lecture-based curriculum ($n = 47$; comparison group). The results revealed significantly higher conceptual and procedural knowledge learning gains following activity with the PILL-VR simulation compared to studying via lecture-based curriculum. PILL-VR exposed the students to their own errors, allowing procedure rehearsal followed by constant feedback which is essential to skill acquisition. Although PILL-VR is based on a desktop system, it facilitated a strong sense of presence. A small positive correlation was found on questionnaire scores between the sense of presence, particularly the sense of control, and conceptual-procedural learning of medication administration. This indicates that by improving students' sense of control in the PILL-VR, the learning process can be improved. Hence, VR simulations may provide affordable and flexible access to practice necessary practical skills in higher education, which is crucial to developing students' expertise.

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1. Introduction

“Practice without theory is blind, theory without practice is sterile” (Karl Marx, 1975, p. 182). In this study, we address the gap between theory and practice in higher education by studying the low-cost and easily accessible training opportunities of virtual reality (VR) simulations. VR environments have been used as educational platforms in many areas including art, architecture, business, sociology, urban planning, game design and health care (review: Delp et al., 2007). The present study

* Corresponding author. Department of Learning, Instruction and Teacher Education, University of Haifa, 199 Aba Khoushy Avenue, Mount Carmel, Haifa, 3498838, Israel.

E-mail address: iduboui@univ.haifa.ac.il (I. Dubovi).

focused on nursing education and applied the Pharmacology InterLeaved Learning Virtual Reality (PILL-VR) environment (Dubovi, Levy, & Dagan, 2015) that supports the learning and practicing of medication administration procedures via a desktop virtual environment.

Many studies have highlighted the theory-practice gap between the theoretical abstractions learned in academic education and the practical skills required for their application in real-world professional practice settings (e.g. Burnet & Smith, 2000; de la Harpe & Radloff, 2000, pp. 165–179). Moreover, practitioners of all sorts, including nurses, report experiencing a noticeable gap between what they have learned in university and what they practice at the working place. Each context has its own intricate set of considerations that need to be addressed in the workplace. With respect to nursing and other health professions, a significant concern worldwide is the limited opportunities available for practicing in the clinical setting, mainly due to a shortage of clinical placement sites and the priority for patient safety (Hayden, Smiley, Alexander, Kardong-Edgren, & Jeffries, 2014). For example, one study found that while nursing students are expected to learn medication administration practices to ensure the safety of their patients, which requires practical procedural knowledge and skills, only 10% of nurse managers believe that those new graduate nurses are ready for administering medications (Berkow, Virkstis, Stewart, & Conway, 2008). Likewise, near-error situations and adverse events are disproportionately associated with treatment by novice nurses (review: Hickerson, Taylor, & Terhaar, 2016).

Medication administration errors were identified as the most common type of error in health care in the USA by the Institute of Medicine's report (Aspden, Wolcott, Bootman & Cronenwett, 2006). It is estimated that at least 44,000 American deaths in hospitals each year are attributed to such errors (Kohn, Corrigan, & Donaldson, 2000), most of which are preventable (Lisby, Nielsen, Brock, & Mainz, 2010), and exceed the number of annual deaths from motor vehicle accidents (43,458) and breast cancer (42,297) (Institute of Medicine of the National Academies, 2006).

The PILL-VR environment is designed as part of a larger architecture aimed at addressing the gap between theory and practice in academic teaching of practical professions, where conceptual, symbolic and experiential understanding of learning components are engaged separately. In this paper, we focus on an experiential space and report our experience of teaching nursing medication administration procedures with PILL-VR simulations.

1.1. Nursing education

Since the days of Florence Nightingale, nursing education has changed significantly, from apprenticeship training at the bedside to academic-based education and training (American Nurses Association, 1965; Institute of Medicine, 2010). Many positive changes have accompanied this shift including nursing research advancements; growing recognition of nursing as a distinct academic discipline and profession; and better patient outcomes (i.e., lower mortality and failure-to-rescue rates; Aiken et al., 2014). However, the limited access to practice nursing skills at the bedside has resulted in students being less able to transfer or apply their knowledge appropriately to the hospital setting (Waldner & Olson, 2007).

The theory-practice gap can be illustrated with the medication administration process. Registered nurses are the primary practitioners responsible for the administration of medication and spend between 20 and 40% of their time on this task (Westbrook, Duffield, Li, & Creswick, 2011). Effective training for medication administration according to protocols is needed as the literature identifies problems in students' application of this knowledge into practice (King, 2004; Manias & Bullock, 2002), and in their lack of confidence (Latter, Yerrell, Rycroft-Malone, & Shaw, 2000).

1.2. Simulations in nursing education

In the nursing domain, promising efforts have been made involving the creation of a variety of simulations for practicing skills in a broad range of professional activities. These simulations are "an attempt to replicate some or nearly all of the essential aspects of a clinical situation so that the situation may be more readily understood and managed when it occurs for real in clinical practice" (Morton, 1995, p. 76). In recent years, low-fidelity patient simulations (LFPS) to high-fidelity patient simulations (HFPS) have become increasingly popular educational tools. However, financial challenges prevent many nursing schools from using these platforms (Lapkin & Levett-Jones, 2011). Non-immersive computer-based VR simulations might be an accessible and affordable strategy, for delivering flexible and broad-ranging scenarios that focus on cognitive and manual skills in nursing. (For a cost utility description see: Kapp & O'Driscoll, 2010; Lapkin & Levett-Jones, 2011; Tuoriniemi & Schott-Baer, 2008; Rothgeb, 2008).

VR is a three-dimensional computer environment. It provides interactive experiences of an alternate reality in which participants are avatars who can move, sense, touch and act upon simulated objects, supporting the perception that these objects really do exist (Ghanbarzadeh, Ghapanchi, Blumenstein, & Talaie-Khoei, 2014). Most users have a sensation of being a part of the virtual environment; a feeling of "being there" which is called a 'sense of presence'. As stated by Witmer and Singer (1998), several factors contribute to the sense of presence: control, realism, distraction and sensory input. Thus, when the user interacts with the environment in a natural realistic manner and controls events, he sees his avatar behaving as expected and the 3D world changing accordingly to his commands, enhancing the sense of presence. VR environments can be classified as immersive and non-immersive. Immersive VR involves a high degree of interactivity and high-cost peripheral devices, i.e., head mounted displays or a room where the walls are projection screens (called CAVE). Non-immersive VR is often called

desktop VR and it is in the form of a window into a virtual world displayed on a computer monitor and the interaction can be made via a mouse (Choi, Dailey-Hebert, & Simmons Estes, 2016, pp. 1–360).

VR have been partially adopted in educational and pedagogical fields, especially in higher education, mainly in the low-immersive form. The main applications of low-immersive VR in higher education settings are: virtual lecturing, a virtual replica of a classroom setting; field trips as individual learning experiences at a museum, hotel; simulations are used for learning processes that are generally difficult to practice in the real world such as flying in the solar system; and game-based experiences (review: Choi et al., 2016). A recent meta-analysis suggests that virtual reality-based instruction in K-12 and higher education are highly effective (Merchant, Goetz, Cifuentes, Keeney-Kennicutt, & Davis, 2014).

Different from university learning in educational fields, research into health care education shows inconsistent evidence regarding non-immersive VR simulation use. A recent meta-analysis (Cook, Erwin, & Triola, 2010), indicated that non-immersive VR simulation contributes negligible differences in knowledge outcomes in comparison to non-computer interventions, including normative instruction (typically lectures). In contrast, another meta-analysis which examined the effect of desktop VR simulations compared to normative methods of instruction, showed a clear positive pooled overall effect of learning gains with VR simulations (Consorti, Mancuso, Nocioni, & Piccolo, 2012).

A combination of the highly effective results in education and the inconclusive evidence in health care both indicate the need for additional designs and research. Moreover, the paucity of research into the processes of learning prompts the current research into students' experiences with VR. Regardless of the educational opportunities that VR affords in nursing research and practice, it has not been extensively used and there are no studies incorporating a large sample of participants. Recent studies exploring the implementation of a virtual hospital unit to train safety treatment, difficult interpersonal communications and priorities in decision making processes (Aebersold, Tschannen, Stephens, Anderson, & Lei, 2012); the teaching of management and decision-making skills in different clinical conditions (Honey, Connor, Veltman, Bodily, & Diener, 2012; Jenson & Forsyth, 2012; McCallum, Ness, & Price, 2011; Smith & Hamilton, 2015); and concepts of disaster triage (Foronda et al., 2016) have all involved very small samples of students ($n \leq 15$). Clearly, teaching via the VR medium is at an early stage and larger cohorts of students are needed to further understand this tool in undergraduate studies (Irwin & Coutts, 2015).

1.3. Research aim

The purpose of this study was to evaluate the effectiveness of the PILL-VR simulation as a large-scale teaching strategy for medication administration among nursing students, as well as to understand the students' experiences in this environment.

1.4. Research questions

- 1) What impact does learning with the PILL-VR environment have upon *conceptual and procedural learning* of the medication administration procedures in comparison to learning with a normative lecture-based curriculum after the intervention and after a five-month duration?
- 2) How does the PILL-VR environment *facilitate learning* of the medication administration procedure in terms of participants' sense of presence in the environment and their performance in the process of conducting procedures in the environment?

2. Methods

2.1. Participants

Participants included volunteer sophomore nursing students in the Nursing Department at a university in Haifa, Israel. The experimental study group was comprised of 104 students. Of these, 82 (78%) students completed both the pre- and post-test questionnaires. The comparison group included 73 students and 47 (65%) had taken both the pre- and post-test evaluations. Together, 129 students completed the pre- and the post-test evaluations.

The comparison group of students receiving the normative lecture-based curriculum were one academic year below the experimental group receiving the PILL-VR training (Fig. 2). The reasons for this were threefold: to enlarge our sample, to reduce diffusion between the intervention and comparison groups by separating them as much as possible, and to prevent any resentful demoralization of comparison group students. Ten experimental group students were randomly selected. They were recorded together with their screen videos while they worked with the environment. There were no statistically significant differences in demographic characteristics and baseline academic achievements between the experimental and the comparison group (Table 1).

The study was conducted following the approval of the university ethics committee (exempt, #165/14).

2.2. Research design

A quasi-experimental pretest-intervention-posttest comparison group design was conducted based on quantitative analysis of questionnaires, video recordings and worksheets (Fig. 2).

2.3. Procedure

The experimental group ($n = 82$) learned with the PILL-VR environment for a total of three hours instead of the normative lecture-based curriculum. Whereas the comparison group ($n = 47$) learned medication administration via the normative lecture-based curriculum only. The lectures were given by two pharmacists using power-point traditional presentations for a total of approximately 3–4 h. Pre- and post-test evaluations were undertaken at the beginning and at the end of each semester (nearly one month before and two months after the activities on the last day of the academic semester). Students in the experimental group who completed the pre-test and post-test questionnaires were requested to fulfill a delayed post-test measure five months after the intervention.

2.4. Data collection instruments

2.4.1. The PILL-VR environment for medication administration

The PILL-VR environment was designed by this research group in early 2014 (Dubovi et al., 2015). The environment was developed with OpenSim, an open source 3D desktop VR multi-platform (http://opensimulator.org/wiki/Main_Page). Development involved 110 h of computer programming, a PhD student, a designated server and its upkeep. The architecture is of a hospital ward (in a hospital on a virtual island) and includes two rooms: 1) a patient room with an animated patient lying on a bed, and 2) a room with a range of medical equipment and a variety of different medications which are available in a medicine cabinet. Patient history and physician orders are available on an electronic medication management cart.

A student participant enters the PILL-VR environment as a nurse-avatar. Initially, the student is invited to explore his/her avatar-body, and perform actions such a moving about, opening cabinets, picking up equipment and reading charts. This exploration phase is designed for 45 min, based on previous studies (Foronda et al., 2016; Ulrich, Farra, Smith, & Hodgson, 2014), as well as on our own pilot study, showing the importance of naïve VR users having sufficient time for environmental acclimation.

After the acclimation, two scenarios (A and B) are presented as basic medication procedural exercises. The student has to learn and apply his/her knowledge by carrying out the following steps: Assessing the patient's clinical condition, interpreting the physician's orders, preparing the medication for administration (e.g. choosing the correct medication, calculating the medication dose), administering it to the patient, and monitoring and evaluating the effectiveness and side-effects of the treatment (Fig. 1).

Table 1

Demographic characteristics and university entrance and course achievements: Comparisons between the experimental and comparison student groups.

	Experimental Group ($n = 82$)	Comparison Group ($n = 47$)	Total ($n = 129$)	Statistics ^a
Age (years)	22.7 ± 2.4	22.9 ± 2.8	23 ± 3	0.64 ($p = 0.52$)
Female	61 (74%)	36 (77%)	97 (75%)	0.078 ($p = 0.78$)
Male	21 (26%)	11 (23%)	32 (25%)	
Arabs:				2.1 ($p = 0.71$)
Muslim	29 (35%)	21 (45%)	50 (39%)	
Christian	17 (21%)	6 (13%)	23 (18%)	
Druze	4 (5%)	3 (6%)	7 (5%)	
Jewish	31 (38%)	16 (34%)	47 (36%)	
Other	1 (1%)	1 (1%)	2 (2%)	
Psychometric Entrance Test score ^b	606 ± 51	594 ± 43	601 ± 48	-1.25 ($p = 0.20$)
Hebrew (YAEL test) score ^c	114 ± 12	115 ± 9	114 ± 11	-0.46 ($p = 0.61$)
Chemistry course score	66 ± 16	75 ± 37	75 ± 37	1.8 ($p = 0.07$)
Microbiology course score	88 ± 8	85 ± 9	87 ± 9	-1.8 ($p = 0.07$)
Cell-biology course score	91 ± 8	90 ± 9	90 ± 9	-0.55 ($p = 0.57$)
Biology course score	91 ± 8	88 ± 11	90 ± 99	-1.12 ($p = 0.21$)

Numbers represented N (%) or Mean ± SD.

^a Based on Chi square test or independent sample *t*-test appropriate.

^b Psychometric Entrance Test is a standardized test in Israel, generally taken as a higher education admission exam. It covers three areas: mathematics, verbal reasoning and English language.

^c The YAEL test is a Hebrew proficiency test. Students who take the Psychometric Entrance Test in any language other than Hebrew are also required to take the YAEL test. Here we report the mean scores of 27 students in the comparison group and 50 in the experimental group who took the YAEL test.

The PILL-VR environment was designed to respond to a student's performance by giving feedback with imbedded video based directions. The environment encourages active exploration with error management instructions including work sheets of guided activities.

2.4.2. Conceptual and procedural learning

2.4.2.1. MAP knowledge questionnaire. The Medication Administration Procedure (MAP) questionnaire was developed specifically for this study in order to assess the conceptual aspects and the practical applications of medication administration guidelines, as well as the students' decision-making and critical-thinking skills. Construct validity was ensured by structuring the questionnaire according to medication management guidelines (Ministry of Health, 2016; National Guideline Clearinghouse, 2012). This was carried out by two pharmacists as well as the nursing faculty. A total of 13 multiple-choice questions which are divided into three sub-scales (1) Medication Administration Sequence; (2) Basic Procedural Concepts (Fig. 3, example A); (3) Reasoning and Accountability (Fig. 3, Example B). The latter subscale was developed at a later stage of the study in response to the pilot data in the first year and was part of the comparison's group post-test but not the pre-test questionnaire. The experimental group responded to identical questionnaires. The questionnaire has a time limit of 10 min. Analysis of the MAP questionnaire using Cronbach alpha yielded a high internal consistency score of 0.78.

2.4.2.2. Demographic questionnaire. This questionnaire requested information about the participant's gender, age and ethnicity. Additionally, university entrance scores and course achievements from the first academic year were collected from the University of Haifa data base.

2.4.3. Facilitation of learning with the PILL-VR environment

2.4.3.1. Presence questionnaire. We used the Presence Questionnaire (PQ) during the study in order to evaluate participants' sense of presence using the PILL-VR environment. The PQ was developed by Witmer and Singer (1998) to measure the degree to which the participant is "... experiencing the computer-generated environment rather than the actual physical locale" (p.225). The instrument addresses three subscales: (1) Involved/Comparison (11 items) refers to the degree of: subjective comparison felt in the VR, the responsiveness of the VR environment to initiated actions, and involvement in the VR environment; (2) Natural (3 items) refers to the degree at which the interactions with the environment felt natural; (3) Interface Quality (3 items) refers to the degree of distraction caused by the quality of the interface. The participants rated their experiences on a 7-point Likert scale from 1 (not at all) to 7 (completely). The PQ was translated to Hebrew and validated by Kizony (2006) with a high internal consistency $\alpha = 0.89$. The overall internal consistency in the current study was $\alpha = 0.88$, similar to previous reports (Witmer & Singer, 1998).

2.4.3.2. Students' worksheets and video recordings. Worksheets were part of the learning environment guiding the activities, providing information and asking questions. These worksheets were also used to capture participants' declarative knowledge regarding medication administration procedures. Additionally, in order to observe first-hand the process of learning with the PILL-VR environment, 10 randomly-selected students were recorded together with their screen videos while they worked at the PILL-VR environment. This information was captured with Camtasia (<https://www.techsmith.com/camtasia.html>).

2.5. Data analysis

2.5.1. Conceptual and procedural learning (MAP knowledge questionnaire)

The MAP questionnaire responses were coded as correct or incorrect answers, and the total score was calculated as the percentage of correct answers. The pre- and post-test results, including the overall score as well as the scores for each of the three subscales, were analyzed with descriptive statistics (Mean, SD). Gained knowledge following the PILL-VR practical training was calculated for each student by: $[(\text{post-test score}) - (\text{pre-test score})]/(\text{pre-test score})$. Then, learning gains descriptive statistics (Median, Mean, SD) was calculated for the experimental and for the comparison groups. The learning gains were compared using a Mann-Whitney *U* test for non-parametric data with an effect size as *r* (Fritz, Morris, & Richler, 2012). For evaluation of learning retention between the three time points in the experimental student group, a repeated measures ANOVA was used.

Data was analyzed using SPSS (version 21, IBM Corporation, Armonk, NY).

2.5.2. Facilitation of learning with the PILL-VR environment

The perception of presence (PQ) was analyzed by computing the mean (and standard deviation [S.D.]) scores for each subscale. We then used a bivariate correlation to determine any associations between the sense of presence in the virtual environment and conceptual and procedural learning.

a. Participants practice the medication administration procedures



b. Participants as nurse-avatars in a virtual ward in the PILL-VR environment



c. A safe arena for learning in which errors are tolerated, revealed and provided with feedback

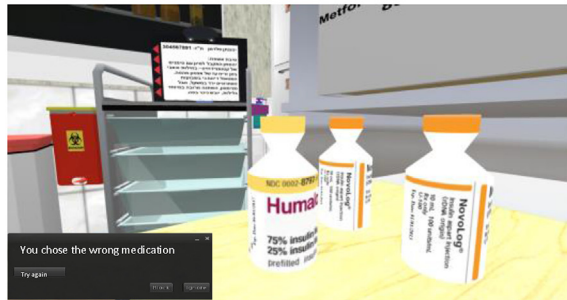


Fig. 1. Photograph and screenshots of students following guided inquiry activities which are scripted as scenarios in the PILL-VR environment.

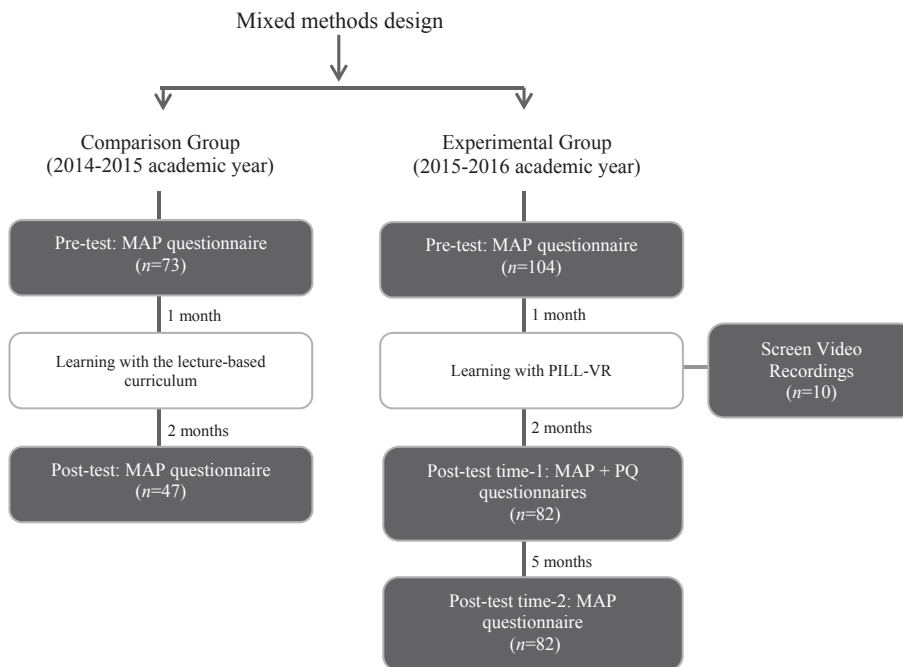


Fig. 2. Flow chart of the study design and procedure.

Example A:

You are presented with two medications which are responsible for glycemic control. Compare the two and then choose the correct answer below:

- A. These two medications have the same trade name but different generic names.
- B. These two medications have different trade names and different generic names.
- C. These two medications have the same trade and generic names.
- D. These two medications have different trade names but the same generic name.

Example B:

The nurse brought Mr. Jacobs his medications that treat high blood pressure and prevent thrombosis (anticoagulants). While Mr. Jacobs took his medications, he accidentally dropped the cup and the pills fell to the ground, scattering around the bed. The nurse needs to decide how manage this situation. Choose the most appropriate decision and explain why you chose it:

A.

I will throw away the pills that fell and I will bring Mr. Jacobs new medications according to his medical records. Additionally, I will report the incident.

B.

I will not administer Mr. Jacobs his medications anew. I will report to the physician about the incident and then I will follow up for his vital signs.

Fig. 3. An example of two questions from the MAP knowledge questionnaire (Example A: the correct answer is D; Example B: The correct answer is B).

To assess the ten students' performance whose activities were captured within the PILL-VR, we measured the amount of time it took to complete the medication administration process, and counted the number of errors. A Wilcoxon Signed-Rank Test of repeated time trials was conducted to compare the performance differences between scenarios A and B.

3. Results

In order to show the sample validity, we compared students who completed both the pre- and the post-test questionnaire to students who did not complete the post-test questionnaire. At the experimental study group no significant difference was found in the pre-test scores up between students who did not complete the post-test questionnaire compared to those who completed both the pre- and the post-test evaluations ($t = -1.29, p = 0.25$). Similarly, at the comparison group no significant difference was found for the pre-test scores between students who did not complete the post-test questionnaire and those who completed both evaluations ($t = -0.30, p = 0.75$).

3.1. Conceptual and procedural learning of the medication administration procedures

Pre-test overall scores on the conceptual and procedural MAP knowledge questionnaire were comparable for the two groups: 55 ± 17 for the experimental group and 51 ± 20 for the comparison group, showing no significant differences (paired $t = -1.08, p = 0.28$). Students' prior knowledge regarding clinical procedures reflects about half of the principles and practices.

Questionnaire scores and learning gains (post – pre-test/pre-test) are presented in Table 2. The experimental group obtained significantly higher scores than the comparison group, with a strong effect size. Their post-test score reaches close 100% possibly showing a ceiling effect. The comparison group did not improve in their overall score.

The experimental group's improvement is true for the overall score as well as all the subscale scores. The highest learning gain was found for the Administration Sequence subscale. Although the Reasoning and Accountability subscale included data

and analysis only for the post-test evaluation, the experimental group obtained a higher mean score than the comparison group (unpaired $t_{(127)} = -3.8, p < 0.001$), with a strong size effect of Cohen's $d = 0.91$.

In order to test for retention, a repeated measures ANOVA with a Greenhouse-Geisser correction was conducted between the pre-test, post-test and the delayed post-test results. It determined that the MAP questionnaire scores differed significantly between the time points ($F(1.62, 113.4) = 251.8, p < 0.001$). Post hoc tests using the Bonferroni correction revealed that there was a significant difference between pre- and post-test evaluations (two months after the experiment; $p < 0.001$). No significant difference was found between the post-test and the delayed post-test evaluation in the experimental group that took place two and five months respectively after the experiment; ($p = 0.14$), showing a retention of medication administration knowledge five months after the PILL-VR training (Fig. 4).

3.2. Facilitation of learning of the medication administration procedure with the PILL-VR environment

3.2.1. Video recordings and students' worksheets

The PILL-VR environment training was accompanied by worksheets the students were required to complete. Students were asked to answer a multiple-choice question during their VR session: "In order to select the right medication, what should you check?" Choices included: name; dose; manufacturing plant; manufacturing date; standardized medicine cabinet, and expiry date. Nine out of ten students answered this question correctly. However, when they were asked in scenario A to select the right medication from the virtual medicine cabinet, nine of the ten students chose the wrong medication. The errors involved omission of the following steps (Fig. 5): 1) failure to check the medication brand name (different drugs could have similar names and packaging); and 2) failure to check the medication expiry date. Students' declarative knowledge of what the steps in the procedure are is complete, as seen in their worksheet pen-and-paper answers. However, their procedural knowledge is only partial as viewed by their performance in the PILL-VR itself. For the first scenario (A), a mean of 2.5 (SD = 1.7) attempts were needed to achieve an errorless performance of medication administration.

The amount of time it took for the ten students to complete the medication administration process was measured. A Wilcoxon Signed-Ranks Test of repeated time trials showed that less time (in minutes) was taken in the second scenario (B) (Median = 0.75) than in scenario A (Median = 4.0), $Z = -2.3, p < 0.05$. The improved performance was also reflected in fewer errors: during scenario A, a median of 3.0 mistakes was performed, which was then reduced to none in scenario B with a median of 0 mistakes, $Z = -2.5, p < 0.05$.

3.2.2. Presence questionnaire

Results revealed that students perceived a high sense of presence while learning with the PILL-VR environment. Our results showed that the three PQ subscales: Involved/Comparison (5.2 ± 0.7), Natural (4.7 ± 1.03) and Interface Quality (5.0 ± 1.1) were either higher or similar to those reported by Witmer and Singer (1998; 5.2 ± 0.8 ; 4.1 ± 1.1 ; 4.8 ± 1.1 , respectively) in their work with immersive VR.

3.2.3. Relation between knowledge and presence scores

A significant though small correlation was found between overall scores on the MAP knowledge questionnaire and the PQ Involved/Control subscale score (Pearson $r = 0.211; p < 0.05$) (Table 3) for the experimental group. We have shown in the

Table 2

Comparisons of pre-test and post-test MAP knowledge questionnaire scores and learning gains between the two groups of students (N = 129).^a

	Pre-test Score		Post-test Score		Learning gain ^b		Statistical tests	
	Exp. (n = 82)	Comparison (n = 47)	Exp. (n = 82)	Comparison (n = 47)	Exp. (n = 82)	Comparison (n = 47)	Mann-Whitney U	Effect size, r
Overall:	55 ± 17	51 ± 20	93 ± 7	52 ± 25	Mdn. = 62, 98 ± 1.3	Mdn. = 6, 6 ± 54,	576***	0.58
Subscales:								
Medication Admin. Sequence	32 ± 24	38 ± 19	83 ± 19	41 ± 24	Mdn. = 100, 111 ± 92	Mdn. = 0, 12 ± 76	728***	0.55
Basic Procedural Concepts	67 ± 24	65 ± 29	98 ± 5	57 ± 31	Mdn. = 50, 68 ± 93	Mdn. = 0, -9 ± 52	649.5***	0.52
Reasoning and Accountability	– ^c	– ^c	96 ± 11	70 ± 46	– ^c	– ^c	– ^c	

Exp, experimental group; comparison, comparison group.

*** $p < 0.001$.

^a Data are presented in percentages - Mean ± SD, Median = Mdn., Range 0-100.

^b Learning gains were computed to take into account differences in prior knowledge before using the PILL-VR training sessions. MAP questionnaire (post-score – pre-score)/(pre-score), i.e. the proportional change from baseline initial understanding of the medication administration requirements.

^c Reasoning and Accountability component was developed at a late stage of this study; consequently, during the pre-test we have no data collected.

section about participants' sense of presence that a high degree of control was gained during the exploration phase of learning with the PILL-VR environment. In the VR, students learned and practiced the medication administration sequence. Therefore, greater learning of the medication sequence was achieved when participants' sense of control was higher.

4. Discussion

Narrowing the gap between theory and practice in education is an ongoing challenge for academic educators of practical professions. In order to demonstrate how the VR environment can integrate learning theoretical knowledge into practice, we examined a particular skill within nursing education; medication administration. The designed environment was the low-cost non-immersive VR desktop system. Nevertheless, our results clearly show that learning medication administration procedures with the PILL-VR supported significantly greater, persistent and consolidated understanding of the practical skills required with respect to learning with the lecture-based curriculum.

The main difference in students' learning outcomes with the PILL-VR versus the normative curriculum involved understanding the medication administration sequence. Procedural understanding of the step-by-step details in the medication administration sequence is a necessary condition for a successful execution. This latter premise can be explained through skill acquisition theory which was outlined by [Fitts and Posner \(1967\)](#) and later by [Anderson \(1983\)](#). They proposed that learning a new skill involves three stages: the cognitive, associative and autonomous stages. Our results regarding the process of learning within VR aligns well with these stages.

The Cognitive stage involves the learner developing an understanding of what the skill comprises. This process encompasses understanding of the behaviors and characteristics required to carry out a skilled performance of a sequence. Our findings show that learning with PILL-VR enhances students' ability to attend to the medication administration procedure. The PILL-VR environment was designed to support learning of a set of steps in medication administration procedures. The VR platform has the advantage of allowing students to acquire information at their own pace, using both visual and auditory sensory channels to process related information. According to Dual Channel theory, this can release the working memory load which leads to better learning ([Baddeley, Eysenck, & Anderson, 2009](#); [Clark & Paivio, 1991](#); [Mayer, 2014](#)). The signaling (or cueing) principle in multimedia learning which refers to the finding that people learn more deeply from a multimedia message when cues are added that guide attention to the relevant elements of the material or highlight the organization of the essential material, provides additional support for this claim ([Mayer, 2014](#)). Having the VR platform provide multisensory cues helps focus students' attention on the relevant task in the environment. These cues work by reducing extraneous cognitive load that distracts attention, and so act to enhance the cognitive learning process.

The Associative stage includes experiential learning. Learners practice and hone their performance based on what they know until efficient patterns of performance emerge. Major errors are detected during this stage and the learner refines responses by identifying which ones are redundant or inefficient. [Anderson \(2009\)](#) explains that at this stage the competence is low and performance is very slow and full of errors. Learning with VR simulation, in contrast to learning from lectures, allows experiential learning and error training. Errors during training are valuable pieces of information because they serve as feedback for one's actions and can point out what aspects of one's knowledge need further correction and refinement.

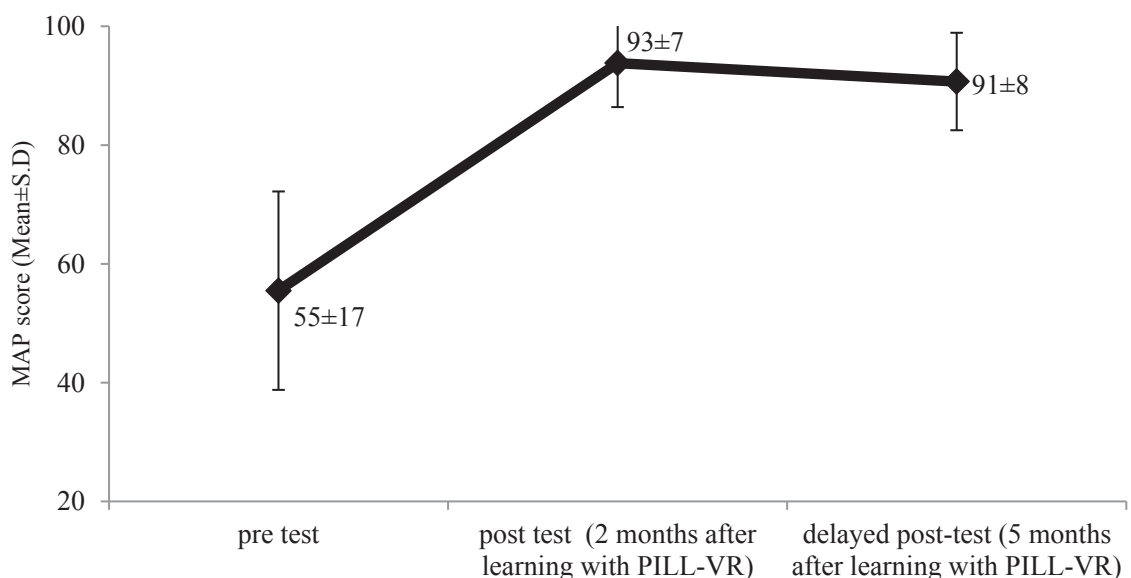


Fig. 4. MAP knowledge questionnaire scores in the experimental group (n = 82) before and after learning with PILL-VR environment.

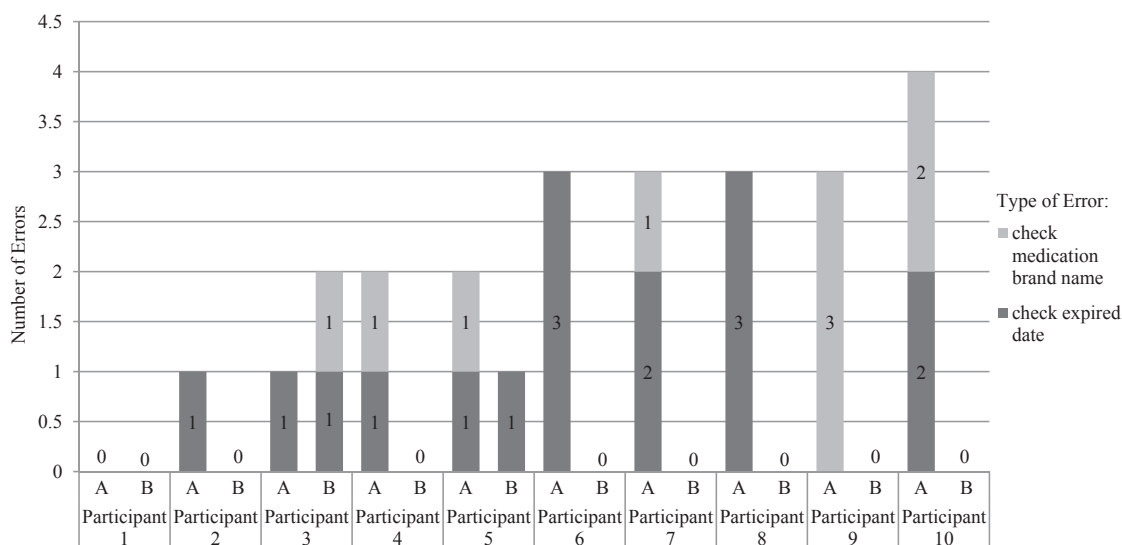


Fig. 5. Type and frequency of medication administration errors made by students ($n = 10$) in scenario A versus in scenario B in the PILL-VR environment.

Table 3

Sense of Presence and Conceptual-Procedural Learning: Results of Pearson's Correlations between the PQ and MAP Scores in Experimental group ($n = 82$).

MAP score	Interface Quality	Natural	Involved/Control
Overall	0.130	-0.009	0.211*
Medication Admin. Sequence	0.047	0.012	0.231*
Basic Procedural Concepts	0.162	0.003	0.173
Reasoning and Accountability	0.126	-0.073	0.025

Data represent the Pearson r .

* $p < 0.05$.

Exposure to errors during initial skill acquisition was found to improve retention, decision making, performance, and transfer of safer practices (Gardner, Abdelfattah, Wiersch, Ahmed, & Willis, 2015; Ivancic IV & Hesketh, 2000; Keith & Frese, 2008). Our study points out that even when participants have correct declarative knowledge, which was acquired during the cognitive stage, they still tend to commit errors while actively applying their procedural knowledge in a VR simulator. The errors are followed by metacognitive strategies of error detection and elimination. This process is very valuable for a nursing student's education as part of their enculturation into common ward practice known as "error recovery" (identifying, interrupting, and correcting a medical error) (Henneman, Blank, Gawlinski, & Henneman, 2006).

Interestingly, our findings show a positive correlation between experiences of the VR and learning: between control, as a subcategory of the sense of presence, and the learning outcomes. Specifically, as the sense of control increases, so does understanding of medication administration procedures. While developing the Presence Questionnaire, Witmer and Singer assumed that an increase in the sense of presence would increase learning and performance, but then they admitted that "yet we have no direct evidence to support our contention" (Witmer & Singer, 1998, p. 239). Although sixteen years have passed since that assumption, there is still little research evidence for that assumption using Witmer and Singer's measurement tool (Tüzün & Özđinç, 2016). In line with Tüzün and Özđinç's conclusions, we show an additional case for supporting this assumption with our positive, though small, correlation results. This result is important as it provides with a design principle for successful VR simulations for learning: ensuring that participants gain sufficient control of the environment is an important condition for learning. Moreover, presence is not a unique attribute of the environment, but it is induced by the fidelity of representation and the high degree of interaction and user control.

The principles of supporting students' active interaction and negotiation with the VR environment are paired with a strong sense of presence in which one feels psychologically present in a virtual context (Dawley & Dede, 2014, pp. 723–734). Generally, the more immersive a virtual environment is, the greater the sense of presence users experience (Gorini, Capideville, De Leo, Mantovani, & Riva, 2011). Although our intervention was based on using a non-immersive desktop VR, we have shown that it facilitates a strong sense of being engaged in the experience, a sense of presence. These findings are consistent with a few studies which showed that also low-immersion systems are capable of providing high-presence experience to users (Lee, Wong, & Fung, 2010). This is important to future development of learning environments, as it shows us that well-designed non-immersive and low-cost desktop VRs can be highly conducive to learning, making them more accessible for learners in higher education.

The Autonomous phase of skill acquisition was not the aim of the short training time with PILL-VR in this study. Nevertheless, our research suggests that training with the desktop VR provides a safe arena allowing students' knowledge to translate from declarative to procedural memory, which is more effective and robust against decay (Kim, Ritter, & Koubek, 2013; Posner, 1973).

4.1. Limitations

The present study has several limitations. Due to the need to prevent diffusion of the treatment between the comparison and the experimental groups, randomization did not apply in this study. Another limitation to our research was the dropout rate just before completing the post-test questionnaires in both, the comparison and the experimental groups. Since participation was voluntarily during a highly stressful semester, many students struggled to find the free time to complete the questionnaires. Furthermore, part of the MAP knowledge questionnaire was developed later, based on the pilot research that was conducted in parallel to the comparison group's learning. Therefore, the comparison group pre-test data does not include the reasoning and accountability subscale. While analyzing how learning with the PILL-VR facilitate learning we had collected randomly only ten video recordings and worksheets.

In order to evaluate the advantages of learning with PILL-VR, further work should be performed on a large scale of different types of healthcare providers (e.g., registered nurses), comparing not just to lecture based education but to other simulation approaches and tools (e.g., high-fidelity patient simulations).

4.2. Conclusion

Simulation provides a mechanism for 'deliberate practice' in a safe, learning environment. Findings of this study revealed that virtual simulations can play a beneficial role in providing an opportunity for deliberate practice, and self-recognition of any potential errors before professional nursing skills are required in a real patient care setting. PILL-VR provides realistic, affordable and flexible possibilities to practice medication administration in any setting where internet access is available, with rehearsal opportunities that may not be possible to practice in real life. This study contributes to the professional education field by suggesting that a VR may provide greater access to practice opportunities in higher education, bridging the gap between the formal and practical learning of professionals, a crucial step in developing students' expertise.

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