Agent-Based Models to Support Bioscience Learning in Nursing Education

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Abstract: This paper reports on a project to support bioscience learning of pharmacology in the undergraduate nursing curriculum. We designed an agent-based learning environment that represents the pharmacokinetic and pharmacodynamic processes in pharmacology. To evaluate nursing students learning with the proposed agent-based environment, we conducted a quasi-experimental study. The results revealed that nursing students who learned with the agent-based environment gained significantly higher conceptual knowledge within the key concepts of pharmacology comparing to students who learned via lecture-based curriculum. These findings suggest an advantage with implementing explanatory agent-based models that point out the essential mechanisms underlying pharmacological phenomena in nursing education.

Introduction

Bioscience understanding has been widely recognized in the literature as fundamental to competent nursing care (Fell et al., 2016). However, in the 1980s, bioscience education was deemphasized in the nursing curriculum leading to the current 'bioscience problem' where nurses are not adequately learning key concepts needed for their work (McVicar, et al., 2015). To promote increased bioscience education in nursing, we demonstrate the learnability of pharmacology, a cornerstone of nursing biosciences education, through the use of an agent-based model learning environment.

Pharmacology knowledge is essential for effective nursing practice because nurses administer and oversee prescribed drug therapies. Nurses spend as much as 40% of their work time on drug-related administration and oversight activities, often serving as the final intermediary between a patient and their drug therapy once it has been prescribed (Westbrook, Duffield, Li & Creswick, 2011). Considering the important and continuing role nurses play in the implementation of drug therapies, this project proposes a new strategy in undergraduate nursing education to enhance nurses' knowledge of fundamental bioscience ideas. More specifically, our approach has been to develop activities and agent-based modeling simulation tools that could be used with nursing students to produce more desirable learning outcomes in the area of pharmacology.

Pharmacology education

Pharmacology is typically taught in nursing education through lectures that emphasize a set of core content including: 1) knowledge of specific drugs and their classes, 2) specific indications of use, dosages and side effects, and 3) some pharmacokinetic and pharmacodynamic processes. *Pharmacokinetics* describe how chemicals are processed in the body, including absorption into the circulatory system, distribution to various tissues, and two routes of drug elimination – metabolization and excretion. For instance, pharmacokinetics would address how different means of drug administration (e.g., oral, intravenous, subcutaneous) would lead to different rates of drug distribution throughout the body. *Pharmacodynamics* describe how the drug affects the body, including within specific macromolecular components in tissues. For instance, pharmacodynamics would address types of drug-receptor interactions.

There are thousands of drugs available for use, and it is unrealistic for a nursing student to memorize all of the individual differences among drug classes. Understanding key concepts of pharmacokinetics and pharmacodynamics can help nurses apply their knowledge across most drugs types and predict with greater accuracy the therapeutic or toxic effects, which is vital for safe medication management. Although nursing students generally find pharmacology to be interesting, it is difficult and they report that their pharmacology skills are low, especially in pharmacokinetics and pharmacodynamics. This is in part because they find the information "appear[s] as list of unconnected facts and labels" (Logan, 2011, pp. 408). These findings highlight the need for new teaching approaches, such as agent-based modeling, to promote comprehension of basic pharmacological concepts.

Agent-based modeling environment

Agent-based modeling (ABM) is a computational modeling paradigm that encodes the behavior of individual agents in simple rules so that a learner can observe the results of these agents' interactions. *NetLogo* is one such modeling environment (Wilensky, 1999) and was used to construct the Pharmacokinetic and Pharmacodynamics

(PkPd) learning environment (Dubovi et al., 2018). Exploration of agent-based models encourages causal thinking in connecting individual behaviors with systemic patterns (Jacobson & Wilensky, 2006). Learning through ABM focuses on entities and their actions (also called micro-level of the system) and global flows (also called macro-level of the system), which allows students to comprehend parallel processes by which emergent phenomena form (Wilensky & Resnick, 1999). Since pharmacological processes are about nonlinear simultaneous interaction of different molecules with one another, with drug molecules (pharmacodynamics processes), and with normal body processes (pharmacokinetic processes), the current study aimed to promote learnability of these concepts through an agent-based modeling paradigm, the PkPd learning environment.

The PkPd learning environment includes several computerized models. One of these models represents the body as comprised of several compartments and was designed especially for the current study. This "compartment model" is a well-established representation in pharmacological textbooks and pharmacokinetics science (Hull, 1979). Within the ABM instantiation of the compartment model, each compartment and their interconnections represent possible pathways for drug molecules: absorption from the digestive system; the bloodstream; distribution and drug molecules distribution to different tissues (e.g., adipose tissue), and drug elimination. While learning with the PkPd model, students can choose the route of drug administration (enteral/topical/parenteral), change the dosage concentration, and manipulate parameters of distribution and elimination processes (amount of muscle and adipose tissue mass). In addition to the representation of compartments, the PkPd environment includes time plots and monitors which show the amounts of drug global actual count (macro-level) that can be easily related by students to what is viewed as happening in the different compartments (micro-level; Figure 1).

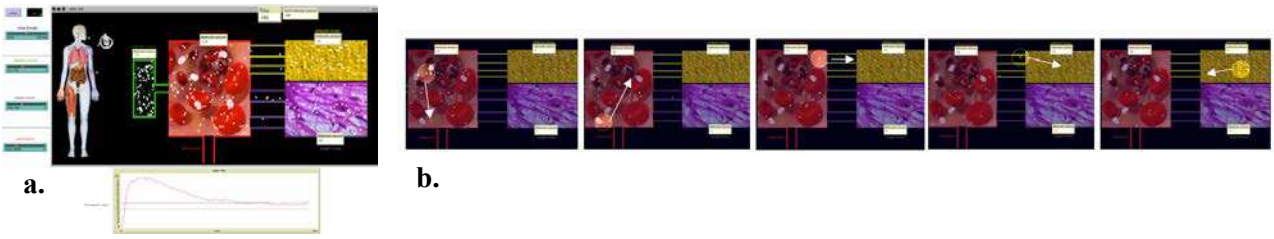

Figure1. The screenshot of PkPd learning environment. **a**. The compartment model, which schematically represents different spaces in the human body, enables exploration of molecules possible pathways for comprehension of pharmacokinetic processes. **b.** Five screen snapshots showing the spotlight effect, which allows students to pay attention to one molecule's path and relate it to global patterns of absorption, distribution and elimination.

Learning with the PkPd environment models was guided by worksheets that provided learning activities. The activities were anchored into different parameters of the system—the micro-level, the macro-level, and the link between them. For example, to enhance understanding of the micro-level, students were asked to choose one molecule in the agent-based model and then follow it while it goes through the absorption, distribution and elimination processes (Figure 1b). Then, we asked students to follow three other molecules and compare their pathways. Since the molecules pathways in the model are random and parallel, we expected that this activity would support causal understanding of the system and link between the different pharmacokinetics concepts (e.g. distribution and elimination), which are interdependent and occur simultaneously.

Methods

Research design, participants and procedure

This study employed a quasi-experimental, controlled pretest–intervention–posttest design with quantitative analysis. Participants included sophomore nursing students who were attending the traditional, lecture-based pharmacological course during the fall semester in the Nursing Department at a university in Israel. The study was comprised of two groups of students: (1) an experimental group (n=89), who learned via the PkPd computer models for approximately 3 to 4 hours; and (2) a comparison group (n=51), who learned via the lecture-based curriculum. The live lectures were presented by two pharmacology experts for a total of 4 hours. The main topics were similar to topics that were emphasized at PkPd environment (i.e., pharmacokinetics parameters such as absorption, distribution and elimination; pharmacodynamics parameters such as drug-receptor interactions). The lecturers used PowerPoint presentations for demonstrations of written material, pictures related to the phenomena, and were based on mathematical formulas. This was typical of lecture-based instruction in undergraduate nursing education at the institution.

Data collection instrument and data analysis

Pharmacokinetics and Pharmacodynamics (PkPd) questionnaire

To assess students' understanding of pharmacokinetics and pharmacodynamics principles, we developed a PkPd questionnaire consisting of 10 questions (8 multiple-choice, 2 open-ended). The items were reviewed by experienced pharmacology lecturers in a university nursing department to ensure appropriate alignment of context and content and that responses could reflect a suitable level of expertise. The questionnaire evaluates the conceptual pharmacology knowledge which is divided into two subscales of pharmacology key concepts: (1) Pharmacokinetics concepts such as absorption, distribution; and elimination; (2) Pharmacodynamics concepts such as drug-receptor interactions affinity and maximum effect. Analysis of the PkPD questionnaire using Cronbach's alpha yielded an internal consistency score of 0.75.

Responses to the PkPd questionnaire were coded as correct or incorrect, and the total score was calculated as the percentage of correct answers. The pre- and post-test results were analyzed with descriptive statistics (Mean, SD). Learning gains were calculated for each student as post-test score minus pre-test score. Then, descriptive statistics for learning gains (Mean, SD) were calculated for the experimental and the comparison groups. Learning gain scores were compared using a Mann–Whitney U test for non-parametric data with an effect size as *r* (Fritz et al., 2012).

Results

The students' pharmacokinetics and pharmacodynamics understanding was assessed with the PkPd questionnaire. Descriptive and inferential statistics for the PkPd pre- and posttest questionnaires are presented in table 1. Overall, the learning gains for the experimental (PkPd) group were significantly higher than those of the comparison group with a medium-to-large effect size. When broken down by subscale, results show that the highest learning gain was found for the two pharmacokinetics subscales—absorption and elimination.

Table 1: Comparisons of pre-test and post-test Questionnaire results: Scores and learning gains for the two student nursing groups (N = 140)*

	Pre-test scores		**Post-test scores**		**Learning gain†**		**Statistical tests**	
	Exp. (*n* = 89)	**Comp. (*n* = 51)**	**Exp. (*n* = 89)**	**Comp. (*n* = 51)**	**Exp. (*n* = 89)**	**Comp. (*n* = 51)**	**Mann–Whitney U**	**Effect size, *r***
Pharmacokinetics	39 ± 19	42 ± 15	75 ± 12	48 ± 24	36± 24 *Mdn.*=38	6 ± 30 *Mdn.*=4	976***	0.48
Pharmacokinetics Subscales								
Absorption	30± 30	34± 33	73 ± 26	43± 41	43± 37 *Mdn.*=50	9 ± 48 *Mdn.*=0	1664***	0.36
Distribution	39± 27	43± 25	65 ± 24	48 ± 29	26 ± 37 *Mdn.*=33	5± 35 *Mdn.*=0	1522***	0.28
Elimination	47 ± 40	48 ± 36	92 ± 18	51 ± 41	45 ± 45 *Mdn.*=50	3± 57 *Mdn.*=0	1337***	0.35
Pharmacodynamics	46 ± 29	55 ± 33	85 ± 25	55± 27	37 ± 38 *Mdn.*=33	0 ± 40 *Mdn.*=0	1124***	0.47

Exp., experimental group; Comp., comparison group.
* Data are presented in percentage mean ± SD, Median=Mdn, Range 0–100.
† Learning gain was computed to compensate for differences in prior knowledge of PDM questionnaire (postscore – prescore).
*** $p < .001$

Discussion

Robust understanding of the basic concepts of pharmacology—pharmacodynamics and pharmacokinetics—may support nurses' clinical decisions related to medication management. Our findings show that students who learned

with PkPd environment gained significantly higher scores for all scales of the PkPd questionnaire than the comparison group who learned with a traditional, lecture-based curriculum. This study adds to a growing body of research showing that agent-based modeling supports learning of many different topics for middle-and high school students (e.g., in physics: Sengupta & Wilensky, 2009). This study suggests that undergraduate students can also strongly benefit from learning with agent-based models. The main difference in students' learning outcomes with the PkPd versus the lecture-based curriculum involved understanding the two pharmacokinetic subscales—absorption and elimination. Drug absorption and elimination are tightly linked to the daily nursing practice of drug administration. Better understanding of these concepts could help nurses more effectively manage the ongoing process of assessment, identify possible complications, and adjust the treatment to patient's individual pathophysiology characteristics.

This study's findings point to the particular advantage of learning with explanatory ABM simulations, which is that they can make visible the essential micro-level mechanisms underlying a phenomenon. Agent-based models enable examination of the different attributes and mechanisms of a system and experimentation with modifications of particular parameters and how they affect the overall macro-behavior of the system. Varying the different attributes and observing their effect on the behavior of the system, can function as a proof of the system mechanism and, hence, build deeper understandings of fundamental content (Wilensky & Rand, 2015).

Future work will expand on the current findings to better articulate the features and affordances of the PkPd that facilitates knowedge integration (Linn, 2005) using qualitative data analysis. Beyond that, we suggest that future work should be comparing learning processes and gains with agent-based models not just with lecture-based education but with other simulated approaches and tools and different manners of deploying agent-based modeling.

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Acknowledgement

We are especially grateful to the nursing students who voluntarily participated in our research and whose insights helped to improve the environment. We thank Mr. Joel Drake for his careful language editing.