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Nursing students learning the pharmacology of diabetes mellitus with complexity-based computerized models: A quasi-experimental study

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ABSTRACT

Background: Pharmacology is a crucial component of medications administration in nursing, yet nursing students generally find it difficult and self-rate their pharmacology skills as low.
Objectives: To evaluate nursing students learning pharmacology with the Pharmacology Inter-Leaved Learning-Cells environment, a novel approach to modeling biochemical interactions using a multiscale, computer-based model with a complexity perspective based on a small set of entities and simple rules. This environment represents molecules, organelles and cells to enhance the understanding of cellular processes, and combines these cells at a higher scale to obtain whole-body interactions.
Participants: Sophomore nursing students who learned the pharmacology of diabetes mellitus with the Pharmacology Inter-Leaved Learning-Cells environment (experimental group; $n = 94$) or via a lecture-based curriculum (comparison group; $n = 54$).
Methods: A quasi-experimental pre- and post-test design was conducted. The Pharmacology-Diabetes-Mellitus questionnaire and the course's final exam were used to evaluate students' knowledge of the pharmacology of diabetes mellitus.
Results: Conceptual learning was significantly higher for the experimental than for the comparison group for the course final exam scores (unpaired $t = -3.8$, $p < 0.001$) and for the Pharmacology-Diabetes-Mellitus questionnaire ($U = 942$, $p < 0.001$). The largest effect size for the Pharmacology-Diabetes-Mellitus questionnaire was for the medication action subscale. Analysis of complex-systems component reasoning revealed a significant difference for micro-macro transitions between the levels ($F(1, 82) = 6.9$, $p < 0.05$).
Conclusions: Learning with complexity-based computerized models is highly effective and enhances the understanding of moving between micro and macro levels of the biochemical phenomena, this is then related to better understanding of medication actions. Moreover, the Pharmacology Inter-Leaved Learning-Cells approach provides a more general reasoning scheme for biochemical processes, which enhances pharmacology learning beyond the specific topic learned. The present study implies that deeper understanding of pharmacology will support nursing students' clinical decisions and empower their proficiency in medications administration.

1. Introduction

Registered nurses are the primary practitioners accountable for the daily preparation and administration of approximately 7000 medication doses and devote 20 to 40% of their time to this task (Westbrook et al., 2011). Near-error situations and adverse events are disproportionately associated with treatment by novice registered nurses (Hickerson et al., 2016). Therefore, a solid and fundamental knowledge of generic drug names and classes, indications of use, dosages and side effects, pharmacokinetics[1] and pharmacodynamics,[2] food and drug interactions, and the medication-administration process should be grounded in nursing education and training (Choo et al., 2010). Teaching safe and effective pharmacotherapy is challenging, however; it is strongly based on the interactions between basic science concepts

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[1] Pharmacokinetics is the study of drug concentrations during the processes of absorption, distribution, biotransformation, and excretion (McKenry et al., 2006). It is common to define these interactions as actions of the body on the drug.

[2] Pharmacodynamics is the study of interactions with specific macromolecular components in tissues, typically receptors (McKenry et al., 2006). It is common to define these processes as actions of the drug on the body.

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of the relevant physiology, anatomy, pathology, and microbiology (Banning and Cortazzi, 2004). Several studies have shown nursing curricula missing the required foundation of knowledge to undertake drug administration effectively and nurses lacking adequate knowledge of pharmacology (Meechan et al., 2011; Ndosi and Newell, 2009). Nurses and nursing students generally find pharmacology to be interesting but difficult, and they self-rate their pharmacology skills as low, especially for pharmacokinetics and pharmacodynamics. Studies have described the traditional education approach as causing "confusion, disinterest, inattentiveness … culminating in underachievement and poor learning outcomes" (Charles and Duffull, 2001; Dilles et al., 2011, p. 396). These findings call for implementing innovative teaching concepts to replace the traditional pharmacology courses methodology (Lim et al., 2014; Thomas and Schuessler, 2016).

1.1. Conceptual Understanding Through the Lens of Complex Systems

The domain of complex systems has evolved rapidly in the past 25 years with the development of novel ideas and tools and new ways of comprehending phenomena via basic and life sciences, computer science, and many other fields. Complex systems comprise micro-level entities (often referred to as *agents*), which interact with each other and with their environment. The interactions of numerous submicroscopic elements result in a higher-order or global behavior, a macro-level phenomenon. Such systems are emergent; although they are not regulated through a central control, they self-organize in coherent global patterns (Holland, 1995; Kauffman, 1995).

A pharmacological process is a prime example of a complex system. Many different molecules interact with one another, with drug molecules (pharmacodynamic processes), and with normal body processes (pharmacokinetic processes) that lead to the emergence of therapeutic or toxic effects (Katzung et al., 2011). Moreover, medications actions are aimed at restoring physiological factors that maintain homeostasis in the body. Homeostasis, as a complex phenomenon, is difficult to teach and to understand (Jacobson and Wilensky, 2006; Zion and Klein, 2015). Since homeostasis means dynamic stability of conditions, it is difficult to understand that equilibrium is a dynamic state (Katzung et al., 2011). Moreover, biological-physiological mechanisms occur simultaneously within interrelated and interdepended systems (such as blood glucose level and condition of stress) (Zion and Klein, 2015). Physiological homeostasis becomes even more complex when abnormal states of multiple morbidities and pharmacological processes change its level. These pharmacodynamic and pharmacokinetic nonlinear interactions within the body's homeostasis are unique for each medication and vary for different patient clinical conditions.

This paper presents the Pharmacology Inter-Leaved Learning-Cells (PILL-Cells) model-based learning environment, which enables students to learn the multi-level biochemical concepts related to diabetic mellitus drug actions, using agent-based computer models (Fig. 1) (Dubovi et al., 2014). The PILL-Cells environment was designed as part of a larger educational architecture aimed at bridging the gap between theory and practice in academic teaching for the nursing profession. The current study builds upon previous research on the value of computer models for learning science, by extending it to understand how models based on a complex-systems perspective may support pharmacology learning. Unique to the design of the computer models included in the environment are two factors. First is the complex-systems-based approach that parses the system to individual micro-level entities (e.g., molecules) and global macro-level phenomena (e.g., hypoglycemia). Second is the multi-level approach: interactions between molecules and organelles emerge into the cell's functioning; interactions between cells in distinct organs emerge into the function of organism as a whole. We hypothesized that double-staged presentation of mechanisms of human organisms increases the learnability of diabetic drug actions.

We selected the diabetic mellitus matter due to the multilevel and complex nature of the glucose–blood equilibrium, its dysregulation with respect to the molecular level and metabolic mechanisms, the organs it involves, and the requirement of polypharmacy management and intensive follow-ups (Bauer and Nauck, 2014).

1.2. Research Aim

The purpose of this study is to evaluate the effectiveness of multi-scale agent-based computer models for complex-systems levels of thinking to support nursing students' learning pharmacology, specifically diabetes molecular and somatic mechanisms and treatment-related medications. Moreover, in the current study we evaluate the use of the computer model environment in transferring conceptual pharmacology knowledge and complex-systems thinking to related topics of pharmacology other than diabetes mellitus.

2. Methods

2.1. Research Design

We conducted a quasi-experimental pre- and post-test design using a quantitative approach.

2.2. Participants and Procedure

Participants included volunteer sophomore nursing students who were attending the traditional lecture-based pharmacological course of 56 h in 14 weeks during the fall semester. The study comprised two groups of students: (1) an experimental group, who learned via the PILL-Cells diabetes pharmacology computer models for approximately 3 to 4 h (Fig. 1); and (2) a comparison group, who learned via the diabetes pharmacology lecture-based curriculum for a total of 4 h. The experimental group included 100 students. Of these, 94 (94%) students completed both the pre- and post-test questionnaires. The comparison group included 80 students, of whom 54 (68%) had taken both the pre- and post-test evaluations. Together, 148 students completed the pre- and the post-test evaluations.

The comparison group was recruited 1 year before the experimental group. Pre- and post-test evaluations were undertaken at the beginning and at the end of the semester (2 months before and 1 month after the activities on the last day of the semester). There were no statistically significant differences in demographic characteristics and baseline academic achievements between the experimental and the comparison groups (Table 1).

2.3. Data Collection Instruments

2.3.1. Pharmacology PILL-Cells Environment

We used an agent-based modeling (ABM)[3] computational paradigm, which is extensively used in the domain of complex systems. ABM has been applied to a wide range of biological and biomedical experiments, particularly for modeling pathophysiological processes with a significant spatial component (An and Wilensky, 2009; Bauer and Nauck, 2014; Bhattacharya et al., 2012). NetLogo[4] is one such modeling environment and was used to construct our PILL-Cells environment (Dubovi et al., 2014; Wilensky, 1999).

Learning with the PILL-Cells environment models was guided by worksheets that provided nursing scenarios, explained the

[3] ABM is a computational modeling paradigm that simulates complex dynamic systems by simulating each of their many autonomous and interacting elements (called entities or agents). By observing and experimenting with agent behaviors and interactions (micro-level), we demonstrate and understand the collective behavior (macro-level) that results from the aggregation of the individual behaviors and interactions.

[4] NetLogo is a widely used, general-purpose, open-source ABM language that enables users to explore and construct models of complex systems (http://ccl.northwestern.edu/netlogo).