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Best practices for teaching pharmacology to undergraduate nursing students: A systematic review of the literature

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ABSTRACT

Objective: In this systematic review we describe best practices for teaching pharmacology to undergraduate baccalaureate nursing students based on the available evidence. Numerous teaching strategies employed in undergraduate pharmacology courses for nursing students have been summarized and compared for their impact on pharmacology knowledge retention, application of pharmacology theory to practice, and student satisfaction. Future directions for research are discussed.

Design: The review was performed using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines for systematic reviews and meta-analyses.

Data Sources: The Cumulative Index of Nursing and Allied Health Literature (CINAHL), Academic Search Complete, Education Resources Information Center (ERIC), and Education Source and Health Reference Centre Academic were searched using key search terms and phrases. Twenty studies, conducted between 2001 and 2017, met the inclusion criteria.

Method: Quality assessment was made in accordance with two appraisal tools: Kirkpatrick's framework and the Medical Education Research Quality Instrument (MERSQI) for quantitative studies.

Results: Online, simulation, and integrated methods of teaching pharmacology were most beneficial for pharmacology knowledge acquisition and student satisfaction. Traditional lecture, problem-based learning, and a flipped classroom were least effective strategies for teaching pharmacology to undergraduate students.

Conclusions: This systematic review will contribute to the body of knowledge used by nurse educators who teach in undergraduate nursing programs, may be particularly useful for undergraduate nursing program directors/administrators who are considering undergoing curricular changes, and may be a conduit for future researchers who wish to design studies aimed at improving teaching and learning within undergraduate nursing education.

1. Introduction

Nurses' roles in medication administration are varied and multifaceted; they include patient assessment, recognizing medication-related patient safety issues such as inappropriate or inaccurate dosages, dosage calculations, various techniques of medication administration, monitoring of medication effects (expected and adverse), and patient education (Cleary-Holdforth and Leufer, 2013; Sulosaari et al., 2012). Newer pharmaceuticals to treat complex illnesses are being rapidly produced and the majority have potentially serious toxicities and adverse drug interactions. Most registered nurses will face the challenge of managing multiple medications for older patients, patients with chronic health problems, and patients with complicated health histories (Keijsers et al., 2012). These patients form the largest group of people admitted to hospital (Health Canada, 2011). As healthcare becomes more complex, pharmacology is an increasingly important component of baccalaureate nursing programs.

Researchers have reported that medication errors are increasing, leading to adverse drug reactions, prolonged hospital stays, and increased costs to the healthcare system (Glaister, 2005; Hunter Revell and McCurry, 2013). These reports raise concerns about the pharmacological knowledge of registered nurses (Likic and Maxwell, 2009). Many authors indicate that one of the primary causes of medication errors is insufficient knowledge of pharmacotherapy (Krahenbuhl-Melcher et al., 2007; Likic and Maxwell, 2009; Meechan et al., 2011).

In this systematic review we describe best practices for teaching pharmacology to undergraduate baccalaureate nursing students based on available evidence. Numerous teaching strategies employed in

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undergraduate pharmacology courses have been summarized and compared for their impact on pharmacology knowledge retention, application of pharmacology theory to practice, and student satisfaction. Future directions for research are discussed.

2. Background

The urgent need to improve pharmacology education in undergraduate nursing programs is driven by the complex nature of pharmacotherapy, high rates of medication errors, and the expanding scope of practice of registered nurses, particularly in relation to pharmaceuticals (Canadian Nurses Association, 2015; Keijsers et al., 2012). Schools of Nursing have a responsibility to ensure effective content delivery of pharmacology theory and skills (including mathematical skills) so that all nursing graduates achieve entry-level competencies for safe patient care. Researchers, however, have suggested that current curricula may not support students to effectively undertake necessary pharmacotherapy roles (Adhikari et al., 2014; McMullan et al., 2010; Meechan et al., 2011; Stolic, 2014). Nursing students have consistently reported feeling dissatisfied with the amount of pharmacology in their programs, leading to uncertainty in critical decision-making and increased anxiety related to medication management (Cleary-Holdforth and Leufer, 2013; Sulosaari et al., 2012). One consistent fear that students and newly graduated nurses report is comprehending and executing complex drug calculations (Cleary-Holdforth and Leufer, 2013; King, 2003; Meechan et al., 2011). Registered nurses who are older or who have higher mathematical qualifications are more able to accurately and safely calculate medication doses, thereby reducing incidents of adverse drug events (Grandell-Niemi et al., 2005; Hunter Revell and McCurry, 2013; McMullan et al., 2010).

It is important to note that changes in nursing curricula (internationally) began when nursing education shifted from a biomedical model to a holistic model of care; resulting in abandonment of separate pharmacology nursing courses and potentially ineffective incorporation of pharmacology content into other courses (Keijsers et al., 2012; Meechan et al., 2011). Some scholars have argued that this shift may have reduced competence among nursing students and practicing nurses (Keijsers et al., 2012; Meechan et al., 2011). More than two decades ago, Wright (2007) began arguing that most undergraduate nursing students were not able to safely calculate drug doses because they lacked basic mathematical concepts for computations such as place value, decimals, fractions, percentages and multiplication. Recently, Malau-Aduli et al. (2013) confirmed that registered nurses do not have sufficient pharmacologic knowledge, and also struggle with dose calculations.

Remarkably, although a wealth of evidence suggests that most nursing students and registered nurses struggle with pharmacotherapeutics and feel ill-equipped for practice (Keijsers et al., 2012; Wiernik, P. H., and Public Policy Committee of the American College of Clinical Pharmacology, 2015), few researchers investigate or describe best practices in pharmacology education for undergraduate nursing students. Most studies about the effectiveness of various teaching strategies have focused solely on medical students.

Currently, pharmacology course delivery and content vary across undergraduate programs; programs often use one or more of the following delivery methods: online or blended (online and lecture), traditional lecture, flipped classroom, problem or case-based learning, simulation, and/or integrated (Barkhouse-Mackeen and Murphy, 2013; Croteau et al., 2011). See Appendix A for a detailed description of each teaching strategy. At present, there are no systematic reviews of best practices for pharmacology education in undergraduate nursing programs.

This systematic review will contribute to the body of knowledge used by nurse educators who teach in undergraduate nursing programs and may be particularly useful for undergraduate nursing program directors/administrators who are considering curricular changes. The review may also be a conduit for future researchers who wish to design studies aimed at improving teaching and learning within undergraduate nursing education.

3. Method

The review was performed using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines for systematic reviews and meta-analyses (Moher et al., 2009; Pope et al., 2007). PRISMA guidelines offer a structured approach for formulating and documenting search strategy and allow for the development of a review that is replicable by other researchers.

3.1. Review Questions

Due to the high volume of health literature, systematic reviews are essential for making informed health-related decisions or practice changes (Hemmingway and Brereton, 2009). Articles are "identified, appraised, and summarized according to pre-defined, explicit methods" to answer specific questions (Chen, 2009, p. 18). This review was guided by the following overarching question: What are best practices for teaching pharmacology to undergraduate nursing students? Three focused sub-questions followed:

1. What are the current (2000–2017) teaching strategies employed in undergraduate baccalaureate nursing programs?
2. What is the impact of each teaching strategy in terms of pharmacology knowledge retention and/or pharmacology skills acquisition for undergraduate nursing students?
3. How do the various strategies impact undergraduate nursing student satisfaction?

3.2. Inclusion and Exclusion Criteria

The search was restricted to: articles written in English, focused on the impact of various teaching strategies associated with pharmacology education on undergraduate nursing students, and published in peer-reviewed journals on or after 2000. Limiting the search to between 2000 and 2017 minimized results for curricula that no longer exist. Non-peer-reviewed articles were not included unless the authors described a specific teaching strategy for pharmacology and assessed the effectiveness of the strategy. Articles were excluded if they were non-English-language, offered anecdotal evidence only, or focused on advanced practice pharmacotherapeutics within graduate (Masters or PhD) nursing programs.

3.3. Search Strategy

The databases Cumulative Index of Nursing and Allied Health Literature (CINAHL), Academic Search Complete, Education Resources Information Center (ERIC), Education Source, and Health Reference Centre Academic were searched using key search terms and phrases summarized in Table 1. All five databases are well-established, current, multi-disciplinary research platforms, holding a wide variety of peer-reviewed journals. One hundred and sixty-nine articles were identified at first. After duplicates were removed and abstracts were reviewed, 17 articles were retained. Reference lists of retained articles were also reviewed and three additional articles were deemed eligible. Exact search queries conducted for each of the databases and number of results appear in Fig. 1.

3.4. Quality Appraisal

Two tools were used to appraise the 20 articles retained: Kirkpatrick's framework (1998) and the Medical Education Research Quality Instrument (MERSQI) for quantitative studies (Reed et al.,

Table 1
Search strategy.

Column A Teaching strategies	Column B Pharmacology education	Column C Undergraduate nurse	Column D Impact
Teaching strategy	Pharmacology education	Nurs*	Impact
Teaching method	Pharmacology knowledge	Student nurs*	Effect*
Course delivery	Pharmacology skills	New nurs*	
Educational strategy	Pharmacology competence		
	Medication education		
	Medication skills		
	Medication competence		
	Drug knowledge		
	Drug calculation*		
	Dosage calculation*		

Key search terms and phrases from Column A were used individually, and in combination with key search terms and phrases from Column B, and Column C using the following Boolean phrasing: "teaching strategy" OR "teaching method" OR "course delivery" AND "pharmacology education" OR "pharmacology knowledge" OR "pharmacology skills" OR "pharmacology competence" OR "medication education" OR "medication knowledge" OR "medication skills" OR "medication competence" OR "drug knowledge" OR "drug calculation*" OR "dosage calculation*" AND "nurs*". Other terms from Column D were included in a secondary search, but did not result in any new, relevant articles.

2008). Kirkpatrick's framework (1967) (as cited in Kirkpatrick and Netlibrary, 1998) is widely used by education experts and researchers to: assess the quality of retrieved research, plan and evaluate educational initiatives, and enhance the quality of their own manuscripts (Keijsers et al., 2012; Sullivan, 2011). There are four components of Kirkpatrick's framework: (1) reaction to learning experience; (2) learning (attitudes, perceptions, knowledge and skills); (3) changes in behaviours; and (4) results (organizational practices changes and/or patient benefits). In this review, points were assigned based on the highest level of outcome on the Kirkpatrick framework (Appendix B). One point was awarded if researchers discussed results in terms of student satisfaction, changes in attitudes, and/or changes in perceptions; one and a half points were awarded if outcomes of an intervention influenced pharmacology knowledge and/or medication administration skill; two points were awarded if an intervention resulted in changes in student behaviours in class or during clinical practice. Three points were awarded when researchers linked their results to patient or healthcare outcome(s). In most studies, researchers provided outcomes that applied to more than one level. To maintain consistency, points were awarded for the highest-level outcome achieved.

The Medical Education Research Quality Instrument (MERSQI) for quantitative studies (Reed et al., 2008) was also used to appraise quality of the research (Appendix C). The MERSQI was selected because of its good inter-rater reliability and content validity (Cook and Reed, 2015; Sullivan, 2011). Additionally, scholars have determined that the 10-item MERSQI is a useful and reliable to appraise methodological rigor and quality of medical education research (Cook and Reed, 2015). Scores for the MERSQI usually range from 5 to 18 points (Reed et al., 2008; Sawatsky et al., 2015). The average score for manuscripts published in an international journal is 10.7 (Reed et al., 2008). Scores of 18 are only assigned to randomized controlled trials (RCTs) meeting exacting specifications (Reed et al., 2008; Sullivan, 2011). In this review, points were assigned to each study based on quality of study design (1–3 points), representativeness of sampling (include response rate) (0.5–3 points), objectivity of data collected (1 or 3 points), validity of evaluation instrument (0–3 points), and appropriateness and complexity of data analysis (0–3 points). The Kirkpatrick and MERSQI score for each of the studies included in this systematic review is provided in the Data Extraction Tables (Appendix D).

3.5. Risk of Bias

Bias can impact validity and reliability of study findings and lead to misinterpretation of data, and harmful consequences for practice (Higgins and Green, 2011; Pannucci and Wilkins, 2010; Smith and Noble, 2014). Sources of bias considered for this review were: selection, sampling, performance, design, detection, confounding, measurement/instrument, attrition, and reporting biases (Table 2). Some form of bias was noted in each of the studies; sampling bias was most common. Selection, and attrition bias were noted in 9 of the included studies (Table 3).

4. Results

Studies varied in design, sample size, and outcome measures. Most investigators chose a single site design (single university) rather than multi-site. The majority of student participants were female, under the age of 25 years. Length of pedagogical intervention varied, ranging from one classroom day (Anderson et al., 2013) to 14 months (Meechan et al., 2011). Most were North American studies (nine in the United States, and one in Canada). The remaining 10 studies were conducted in Belgium (1), Turkey (1), India (2), Australia (2), Italy (1), Taiwan (1) and the United Kingdom (2). Results are presented according to the teaching strategies employed in undergraduate education for nurses: online or blended (online and lecture), traditional lecture, flipped classroom, problem or case-based learning, simulation, and integrated.

4.1. Online or Blended Learning

Multiple investigators compared the impact of online learning to either traditional lectures or other teaching strategies and most found a positive correlation between pharmacology content delivered online and improved outcomes for students (Devi et al., 2010; Devi et al., 2013; Glaister, 2005; Holland et al., 2013; Jeffries, 2001; Mackie and Bruce, 2016; Sowan and Abdu-Idhail, 2014). In this review, we defined online learning as purely online or blended learning (online and lecture), as in much of the literature authors have used these two definitions interchangeably.

In one multi-site study, Van Lanker et al. (2016) used a pre-and post-test consisting of 16 dosage calculation exercises to compare an e-learning course to face-to-face lectures for students in their final year of nursing school. Students who received face-to-face lectures received statistically significantly higher scores compared to students who received the e-learning course, and improvements were sustained at 3 months post course. In seven studies, however, authors reported superior pharmacology knowledge (measured by multiple choice tests) or superior scores (measured by medication dosage calculation tests) in students who were taught pharmacology content online, compared to students who were taught similar content via traditional lectures or integrated learning (Devi et al., 2010, 2013; Glaister, 2005; Jeffries, 2001; Lee and Lin, 2013; Mackie and Bruce, 2016; McMullan et al., 2011).

Researchers have also found that online learning enhances pharmacological procedural knowledge, which is knowledge gained through pharmacological demonstrations (Devi et al., 2010, 2013; Sowan and Abdu-Idhail, 2014). Devi et al. (2010, 2013) found that students who received a demonstration of medication administration via video were more adept at providing consistent and effective patient education to their patients, better at resolving their patients' concerns and provided essential information on adverse effects of medications compared to students who received a similar demonstration as a lecture. Sowan and Abdu-Idhail (2014) obtained similar results after provided undergraduate nursing students with an online two-and-a-half-week course containing videos of fundamental medication administration skills for enteral and parenteral drug administration. Students who viewed online videos were better at procedural steps in enteral and parenteral

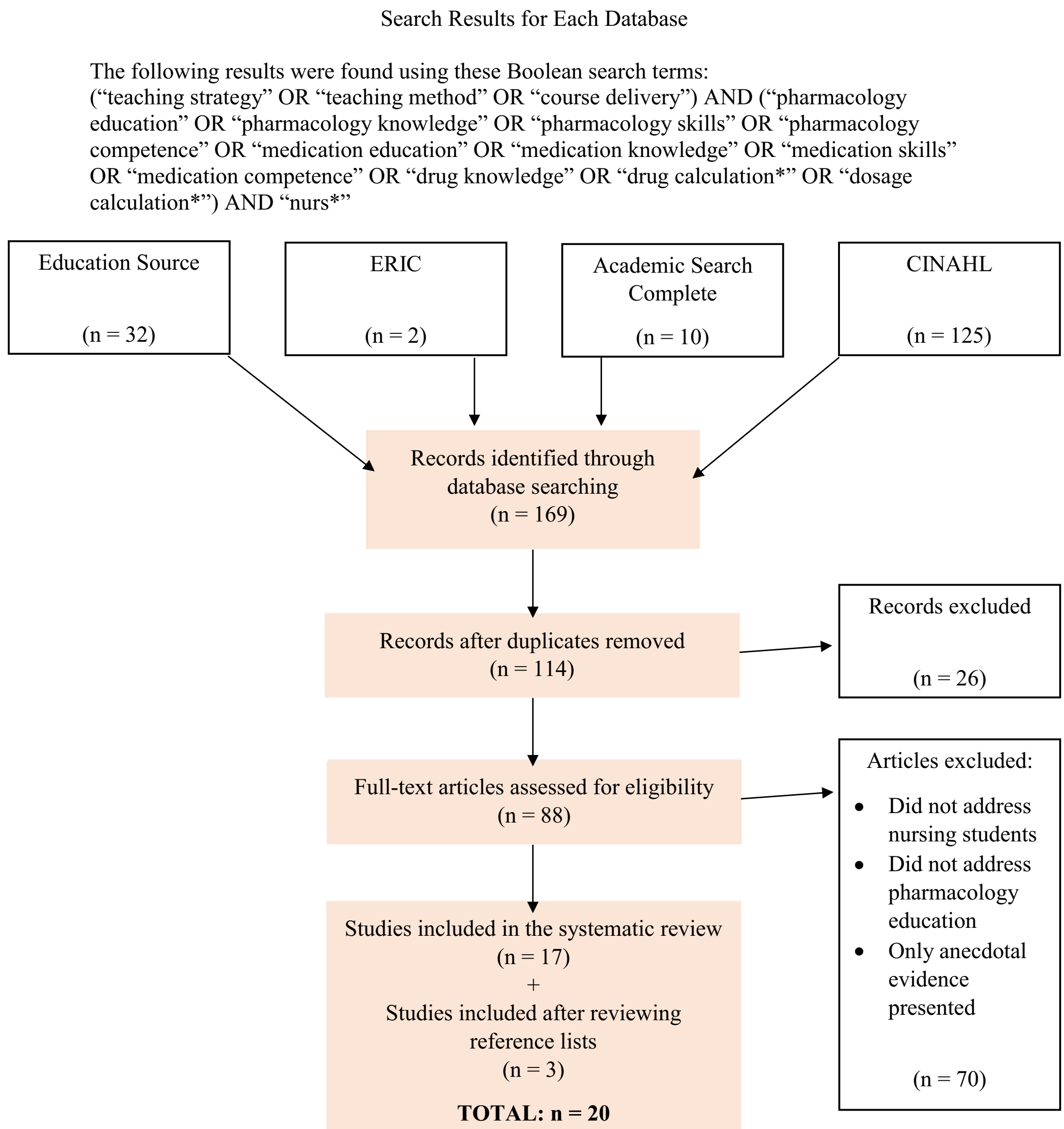

Fig. 1. Search results for each database.
The following results were found using these Boolean search terms:
("teaching strategy" OR "teaching method" OR "course delivery") AND ("pharmacology education" OR "pharmacology knowledge" OR "pharmacology skills" OR "pharmacology competence" OR "medication education" OR "medication knowledge" OR "medication skills" OR "medication competence" OR "drug knowledge" OR "drug calculation*" OR "dosage calculation*") AND "nurs*".

drug administration, including both psychomotor and communication skills, compared to a previous cohort of students who received traditional instruction. Finally, after testing student oral medication administration performance using an 8 station Objective Structured Clinical Examination (OSCE), Holland et al. (2013) concluded that an additional online clinical skills video focused on oral medication administration was especially helpful for students who were at risk of failing, although the same online video did not have a significant effect on students who were already doing well in the pharmacology course.

Researchers report mixed findings for student satisfaction with online learning in pharmacology. Even though students were satisfied with an online approach, approximately 60% of the students in Sowan and Abdu-Idhail's (2014) study reported that they preferred online learning as a supplement rather than a replacement of face-to-face lectures or laboratory sessions. Similarly, when Glaister (2005) analyzed focus group responses, students who were provided with extensive independent online practice in dosage calculations indicated that they did not consider it useful even though they were provided with immediate informative feedback and were free to access this program, or not, on a self-determined basis. In contrast, the students in Devi et al.'s (2013) study reported that they were "easily bored by [pharmacology] lectures which are monotonous and with no active learning materials" (p. 71).

4.2. *Traditional Lectures*

In one study, students who received traditional lectures were better at drug-calculation skills such as intravenous flow rate calculations and conversion of measurement units compared to students who received the same content in small groups (Basak and Yildiz, 2014). In another, researchers who compared exam results found no statistically significant differences in knowledge retention or skills acquisition between students who received traditional lectures and students who received newer, more innovative strategies such as flipped classroom or online, interactive pharmacology modules (Geist et al., 2015). In three studies, researchers found that if students received pharmacology content via

Table 2
Types of bias.
Adapted from: Higgins, J., Green, S. (editors). Cochrane Handbook for Systematic Reviews of Interventions Version 5.1.0 [updated March 2011]. The Cochrane Collaboration, 2011. Available from www.cochrane-handbook.org.

Bias	Definition
Selection bias	Selection bias refers to baseline differences of the compared groups; this can occur during identification of the study population. Randomized controlled trials, and other prospective studies, have a low risk of selection bias since the outcome is unknown at the time of enrolment and a random sequence is used to separate the study population in cohorts.
Sampling bias	Sampling bias is a bias in which a sample is collected in such a way that some members of the intended population are less likely to be included than others.
Performance bias	Performance bias happens when one group of subjects in an experiment gets more attention from investigators than another group. The difference in care levels result in systematic differences between groups, making it difficult or impossible to conclude that an intervention caused an effect, as opposed to level of care.
Detection bias	Detection bias refers to systematic differences between groups in how outcomes are determined. Blinding (or masking) of outcome assessors may reduce the risk that knowledge of which intervention was received, rather than the intervention itself, affects outcome measurement. Blinding of outcome assessors can be especially important for assessment of subjective outcomes, such as degree of postoperative pain.
Attrition bias	Attrition bias refers to differences between groups in withdrawals from a study. Withdrawals from the study lead to incomplete outcome data.
Reporting bias	Reporting bias refers to systematic differences between reported and unreported findings. Within a published report those analyses with statistically significant differences between intervention groups are more likely to be reported than non-significant differences.
Contamination bias	Contamination bias occurs when members of the ‘control’ group inadvertently receive the treatment or are exposed to the intervention, thus potentially minimizing the difference in outcomes between the two groups.
Confounding bias	A situation in which the effect between an exposure and outcome is distorted by the presence of another variable.
Participant bias	Participant bias is a tendency of participants in an experiment to consciously or subconsciously act in a way that they think the experimenter/researcher wants them to act. It often occurs when subjects realize or know the purpose of the study.
Design bias	Design bias is introduced when the researcher fails to take into account the inherent biases liable in most types of experiment.
Measurement bias	Measurement bias exists when the measurement tool favors a particular result. A measurement process is biased if it systematically overstates or understates the true value of the measurement.

face-to-face lectures, their general knowledge and practical skills (for example, their abilities to effectively relay necessary information about the various medications to patients) were inferior compared to students who received similar pharmacology content electronically (Jeffries, 2001; Devi et al., 2010; Devi et al., 2013). With regards to student satisfaction, authors suggest that students who receive pharmacology content via lecture are less satisfied than students who receive online pharmacology content (Devi et al., 2013; Jeffries, 2001).

4.3. The Flipped Classroom

Although a number of articles and books have been written about flipped classrooms in general (Betihavas et al., 2016; Harrington et al., 2015; Njie-Carr et al., 2016), we only found two studies focused on flipped classrooms for pharmacology in nursing education. Geist et al. (2015) found that although students in a flipped classroom performed better during midterm quizzes than students in a traditional lecture, when the final exam results were compared, there were no statistically significant differences in pharmacology knowledge or skills between the two groups. Hanson (2016) used an evaluative questionnaire to examine experiences and perceptions of undergraduate nursing students enrolled in a flipped pharmacology classroom but made no comparison to any other methods of teaching; all students who participated in the study were enrolled in the flipped classroom. Some students reported that the flipped classroom improved their comprehension of pharmacology content, while others stated the method had minimal or no benefit for learning. Some students shared that the flipped classroom competed with other commitments (family, work, other courses) and that they had a preference for conventional instructional learning. The data collection methods changed mid-study and only 13% of the students across two cohorts completed the evaluative questionnaire, so the results are limited.

4.4. Problem-based Learning/Cooperative Learning

Few nurse educators have examined problem-based or cooperative learning in a pharmacology classroom. Of three articles retrieved, only one was an empirical article; in two the authors presented anecdotal evidence only. Basak and Yildiz (2014) examined differences in drug calculation skills between nursing students who received cooperative learning and nursing students who received traditional lectures. All students completed a 20-item multiple choice pre and post-test consisting dosage calculations for enteral and parental drugs, intravenous flow rate calculations, and conversion of measurement units. Eighty-five percent of the students in the traditional lecture group scored 90% or higher in the post-test, compared to only 71.9% of students in the cooperative learning group. The authors did not examine student satisfaction.

4.5. Simulation

Of four quasi-experimental studies designed to test outcomes of simulation in pharmacology education, only one study included a control group (Harris et al., 2014). Harris and colleagues used a post-test only design to compare traditional didactic methods of teaching to low fidelity simulation stations, using a 19-item medication calculation exam. Students in the control group (n = 79) attended a lecture on medication administration. Students in the simulation group (n = 79) rotated through three low-fidelity simulation stations in groups of four. Students who attended the simulation stations had statistically significantly higher scores on the exam compared to students who attended the lecture.

Three studies used a one-group pre and post-test design (Costello, 2011; Grugnetti et al., 2014; Lancaster, 2014). All authors attributed the differences between pre and post-tests as attributable to simulation. Because there were no control groups, the inference is speculative. In a small group of students (n = 24), Costello (2011) found that dosage calculation scores improved considerably immediately following low fidelity simulation consisting of eight medication calculation stations beginning with oral medication and ending with intravenous calculations. Improvements were still evident at one and six months post simulation. Grugnetti et al. (2013) used a 30-item dosage calculation test to assess the effectiveness of a clinical skills workshop for drug-dose calculations. After 30 h of simulation the students' drug-dosage calculation skills and understanding of dosage calculations improved. Lancaster (2014) also used a one group pre and post-test design to measure knowledge acquisition after online serious game simulation. Lancaster concluded that students' knowledge of patient-controlled analgesia, abilities to recognize signs and symptoms of opioid overdose, and the need for a reversal agent improved with online serious gaming simulation. Students reported that they were satisfied with serious game simulation in pharmacology. The online pre and post-tests were

Table 3
Limitations and potential for bias for individual studies.

Citation	Limitations	Potential for Bias
Anderson et al. (2013)	Pilot project. The data collection tool was instructor generated and lacked reliability and validity statistics. The focus of the project was on perceptions of the technology; no attempt was made to obtain objective data regarding actual learning that occurred.	Selection bias and performance/detection bias
Basak and Yildiz (2014)	Small sample size, representing the students enrolled in a single school.	Selection bias and sampling bias
Costello (2011)	Project limited to one small baccalaureate nursing program in a private college in the Northeastern United States; results of the project are not generalizable to the larger population of students in nursing programs across the United States or in other countries.	Selection bias
Devi et al. (2010)	Possibility of students sharing information between groups.	Selection bias and contamination bias
Devi et al. (2013)	Participants recruited from two universities, but were not randomized.	Selection bias
Geist et al. (2015)	Sample recruited from a single university, which may hinder generalizability of the results.	Sampling bias
Glaister (2005)	A quasi-experimental study. Sample recruited from a single university, which may hinder generalizability of the results.	Confounding bias Sampling bias
Grugnetti et al. (2014)	Sample obtained from a single university with a relatively small sample population, which may hinder the generalizability of the results. Study outcomes limited to short-term results.	Sampling bias and risk for attrition bias
Hanson (2016)	Sample from a single university, which may hinder generalizability of the results. Low number of respondents overall. Students who completed the questionnaire may have been those already most engaged by science-based subjects or motivated to influence change in the nursing programme. Inconsistent study design (no pretest in 2013; pre-test in 2014 cohort, but with only 6 respondents).	Sampling bias, attrition bias, participant bias, and design bias
Harris et al. (2014)	Small study sample, from a single university, which may hinder generalizability of the results. Only assessed effect of simulation on medication administration exam.	Sampling bias
Holland et al. (2013)	The Student Satisfaction Questionnaire inhibited follow up and resulted in a low return, especially for the Intervention group (27%). Randomisation of the sample was not possible due to the cohort study design. Results were limited to two intakes of students from a single institution. The students were learning a specific skill and therefore may not be representative of students in different settings who are learning different skills. The researchers did not test knowledge retention.	Attrition bias, selection bias, sampling bias, and reporting bias
Jeffries (2001)	The estimate of internal consistency for the pre-tests and post-tests, was determined to be low. Effects were measured in a single sample. The same test items were used on both the pre-test and post-test.	Measurement bias, sampling bias, and measurement bias
Lancaster (2014)	Sample obtained from a single university, which may hinder generalizability of the results. The serious game simulation occurred in a traditional lecture hall. Believability of the simulation may have been affected by the size of the room, presence of laptops, and interaction between students. Presence of confounding variables.	Sampling bias, confounding bias, and design/ measurement bias
Lee and Lin (2013)	Sample obtained from a single university, which may hinder generalizability of the results. Historical comparison design. The e-learning program was a supplement for the second group of students. Except for gender, there were significant differences found among students' variables (age, nursing program, and whether or not they had graduated from junior college in nursing)	Sampling bias, confounding bias
Mackie and Bruce (2016)	Sample obtained from a single university, which may hinder generalizability of the results. Validity and reliability of the instruments were not discussed in article.	Sampling bias and potential measurement bias
McMullan et al. (2011)	Two cohorts of nursing students enrolled at a single university but at geographically different sites. Sites, rather than individuals, were randomly allocated to either being intervention or control group.	Rigorous study to reduce potential of bias. Potential for detection bias and confounding bias
Meechan et al. (2011)	Sample obtained from a single university, which may hinder generalizability of the results.	Sampling bias
Sowan and Abdu-Idhail (2014)	Sample recruited from a single university, which may hinder generalizability of the results. Researchers measured impact of intervention after 2.5 weeks, with no long-term follow-up. Used previous cohort as control group, without specifying numbers. The authors listed the following limitations: the examined skills were limited to medication administration skills because of budget constraints and the pedagogical method and use of the self-reported data could have biased students' responses.	Sampling bias and measurement bias
Van Lanker et al. (2016)	From a random selection of 20 schools, 7 nursing schools were selected for an e-learning course on dosage calculation, 6 schools were selected for face-to-face lectures containing same content. Some schools did not have computers so random assignment was not possible.	Rigorous study to reduce potential of bias. potential for detection bias and confounding bias
Zellner et al. (2003)	Convenience sample and retrospective study.	Selection bias and potential information bias

not proctored, however, and several confounding variables (pre-readings, audio-visual clips to review, and abilities of students to discuss the situation with others during the simulation) may have influenced the outcome.

In a study focused solely on student perceptions of learning and satisfaction with avatar technology (Anderson et al., 2013), most students reported that avatar technology was an interesting and enjoyable learning experience, easy to use, and helped them apply pharmacology content to a realistic patient situation.

4.6. Integrated Curriculum

Researchers in two studies examined the impact of an integrated curriculum by comparing an integrated curriculum to a curriculum containing separate, stand-alone courses in pharmacology (Meechan et al., 2011; Zellner et al., 2003). To assess outcomes, Meechan et al. (2011) used a patient case study, a 69-item short answer questionnaire, a 42-item online test exploring principles of pharmacokinetics, and a self-assessment of confidence in relation to knowledge of the described medications. Zellner et al. (2003), on the other hand, assessed outcomes using a national pharmacology examination.

Meechan et al. (2011) found that nursing students exposed to an integrated curriculum demonstrated statistically significantly superior pharmacokinetic knowledge and were more able to apply drug knowledge to the patient case than nursing students who received a stand-alone pharmacology course. Patient education scores, however, were not statistically significantly different. Students who received a stand-alone pharmacology course consistently reported higher levels of confidence compared to students who received the integrated curriculum, even though their scores were not as good as students who received the integrated curriculum (Meechan et al., 2011). Zellner and colleagues found no statistically significant differences in test scores between students enrolled in an integrated curriculum and students enrolled in a stand-alone pharmacology course, with regards to calculation skills and effects of medication. Students who received the integrated curriculum, however, performed statistically significantly better on principles of medication administration compared to students who received the separate pharmacology course.

5. Discussion and Conclusion

MERSQI scores for studies included in this systematic review ranged from 7 to 15.5 out of a total 18 points. MERSQI scores usually range from 5 to 18 points (Reed et al., 2008; Sawatsky et al., 2015) therefore the studies were of moderate quality. Although most authors did not test for sustainability of project outcomes, overall results indicate that online, simulation, and integrated methods of teaching pharmacology can positively impact pharmacology knowledge acquisition and student satisfaction. Additional benefits of online learning include convenience, reduced content delivery time, flexibility, and opportunities for students to work collaboratively (Mackie and Bruce, 2016). Researchers who focused on simulation all concluded that simulation improved pharmacology knowledge of undergraduate students and was a better teaching method for skills acquisition (such as medication administration) than a lecture. Of four studies designed to test outcomes of simulation, however, only one study included a control group. Researchers who focused on integrated curricula versus stand-alone pharmacology courses demonstrated that nursing students may feel more confident when offered a stand-alone course, but an integrated pharmacology curriculum is more likely to produce better outcomes for the students. These authors theorized that it is easier for nursing students to assimilate pharmacological information in an integrated curriculum because lecture content on pathophysiology of disease, related pharmacology, and nursing care is combined and reiterated in other courses and clinical practice experiences.

Traditional lecture, problem-based learning and flipped classroom were the least effective strategies for teaching pharmacology to undergraduate students. Major limitations of traditional lectures were: inability of students to easily transfer lecture content to hospital settings, monotony, failure of instructor to effectively demonstrate pharmacological nursing skills due to large class sizes, crowded classrooms that could impede the flow of discussion, and limited practice of procedures by individual students (Devi et al., 2013; Sowan and Abdu-Idhail, 2014).

Student satisfaction was examined in eight of the 20 studies. Student satisfaction is an important assessment variable for researchers; it is a reliable indicator of students' experiences and can spotlight areas of success and areas requiring further improvement in a curriculum. Although students were satisfied with an online approach, most students reported that they preferred to use online tools as a supplement rather than as a replacement for face-to-face lectures or laboratory sessions (Glaister, 2005; Sowan and Abdu-Idhail, 2014). Students seemed to be most satisfied with simulation, felt confident engaging in game simulation (Lancaster, 2014) and reported that avatar technology was an interesting and enjoyable learning experience, easy to use, and helped them apply pharmacology content to realistic patient situations (Anderson et al., 2013). Students were less satisfied with traditional, online and flipped methods of teaching. Student satisfaction was not assessed for problem-based learning or integrated curriculum.

Behaviour change outcomes were reported in only two articles, both from the same authors. Assessing behaviour change is increasingly important in pharmacology education as nurses' roles in educating patients about their medications have grown. Devi et al. (2010, 2013) reported that students who received online pharmacological instruction were more effective at providing patient education; patients who received care from students who received online pharmacological instruction had a better understanding of usage of their prescribed drugs compared to patients of students who received lectures. All other articles reviewed focused on lower level outcomes such as eliciting feedback on the teaching method, changes in perceptions after exposure to different teaching methods, knowledge acquisition and skills acquisition.

6. Implications for Future Research

When studying the effects of teaching interventions in undergraduate programs, it is often not practical to randomize students to an intervention and control group or ethical to provide only some of the students with an intervention that could be potentially enriching or harmful for them (increase or decrease their scores in exams or final grades). Most researchers, therefore, rely on quasi-experimental designs. Even though an important component of a quasi-experimental study is the use of pretesting or analysis of prior achievement to establish group equivalence, in this review, some studies contained only one group with pre-test post-test or post-test only. An alternative to ensure that all students eventually receive the intervention is repeated measures or cross-over design. There is also a dearth of information about behaviour change or sustainability of outcomes. Since most undergraduate nursing programs are four years in length, future researchers could focus on the long-term impact of different teaching strategies on student behaviours or pharmacology knowledge retention. Finally, gaming, simulation and online teaching formats are promising and satisfying for the largest population of students entering nursing schools (millennial generation), so more studies focused on these teaching strategies are warranted.

In closing, we observed that many researchers focused intently on dosage calculation skills rather than pharmacotherapeutics. However, dosage calculation knowledge may only reflect the student's mathematical skills and not necessarily their pharmacology knowledge. This is a limitation of some of the literature included in this review, and therefore a potential limitation of the review itself. Future research on pharmacology education in undergraduate nursing programs ought to focus on pharmacotherapeutics, rather than mathematical skills. Additionally, in the future, it may be necessary to collaborate with educational partners to ensure that students who enter a university program already have the requisite basic mathematical skills.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.nedt.2018.11.017.

Appendix A. Description of Teaching Strategies

Traditional lecture	Traditional lecture is a didactic teaching method. Oral presentations are delivered by an instructor in order to relay necessary knowledge to students (Rohwer and Wandberg, 2005). Traditional lectures are common in undergraduate nursing programs, due in large part to cost-effectiveness and convenience of delivery (Jeffries, 2000; Miller, 2003; Sherman, Comer, Putnam & Freeman, 2012). Critics of traditional lectures assert that this teaching method is ineffective and should be removed from undergraduate nursing programs because the method does not always account for learning pace, previous experience and knowledge, the learner's interest in the content, and/or the learner's time (Jeffries, 2001; Devi et al., 2010, 2013). Conversely, So (2009) and McCain (2008) argue that traditional lectures are necessary for student success because the method allows for collaboration, sharing of ideas and instant responses to questions from instructors and/or peers.

Online/blended	Online learning is a form of distance education that has been increasingly selected by nursing schools as a cost effective and attractive teaching option aimed at improving student access to credit courses (McKenzie and Murray, 2010). Online teaching methodologies are strictly computer-based. Students review class material independently (usually on learning management systems) and are often required to engage in online discussions about relevant topics with their instructor and their peers (Blissit, 2016; Sherman, Putman, Comer & Freeman, 2012). Blended courses, on the other hand, are a blend of online and lecture. In these courses students are still expected to review course materials independently, but they also attend a reduced number of scheduled classes for small or large group discussions on relevant material (Blissit, 2016). For the purpose of this literature review purely online learning and blended learning were considered to be online learning, as in much of the literature, authors have used these two definitions interchangeably.
Flipped classroom	In a flipped classroom, lecture and assignment components of a pharmacology course are reversed. Activities that may have traditionally been considered homework, are moved into the classroom (Abeysekera and Dawson, 2015; Ferreri and O'Connor, 2013; Tucker, 2012). Currently, this approach to teaching in undergraduate nursing programs is heavily promoted (Betihavas et al., 2016; Holman and Hanson, 2016), but the evidence for flipped classrooms is inconsistent (Harrington et al., 2015; Njie-Carr et al., 2016).
Problem based learning	Problem-based learning (PBL) is an approach to higher education that has been adopted in many nursing schools, nationally and internationally. PBL and cooperative learning (COL) are based on the principle that students work in collaboration in small groups to achieve shared learning objectives. Both methods use interactive learning-teaching approaches, and are comprised of five main components: positive interdependence (each group member is aware of his/her responsibility for the others' learning), individual accountability (each member contributes to the group, within his or her own potential, in order to achieve the goal), face-to-face interaction (members meet to facilitate discussion, encourage and support each member's contributions), social skills (members must have and/or must develop interpersonal communication skills), and group processing (members evaluate themselves and the group) (Basak and Yildiz, 2014; Harding and Petrick, 2008). During PBL, students apply learned theories to actual clinical scenarios (Sachidananda and Adiga, 2010; Zhang, 2014) and in theory they are motivated "to actively seek relevant knowledge using all possible resources" (Zhang, 2014, p. 1).
Simulation	In simulation-based nursing education, simulation aids to replicate clinical scenarios. Simulation aids range from low-fidelity mannequins to high fidelity mannequins, to real actors, who play out actual clinical scenarios to allow students to safely learn relevant course material (Abdulmohsen, 2010). Serious gaming, role playing, computer-assisted instruction, and virtual simulation scenarios with avatars are also becoming more common in clinical instruction.
Integrated	In an integrated curriculum, pharmacological content (typically taught in separate, stand-alone courses) is integrated or threaded throughout most or all the courses in the curriculum (Lim and Honey, 2006). Usually, core pharmacological concepts (for example fluid and electrolyte balance) are reviewed in relation to nursing care theory and pathophysiology and these concepts are quickly put into practice via clinical experiences associated with the course. According to Bhardwaj et al. (2015) an integrated method of teaching pharmacology content provides students with holistic, rather than fragmented learning perspectives. It may also be easier for nursing students to assimilate pharmacological content when information on pathophysiology of disease, related pharmacology, and nursing care is combined, making assimilation of pharmacological information easier (Zellner, 2003). Additional advantages include enhanced learning of basic concepts, decreased repetition of content, and clear emphasis on nursing practice (Bhardwaj et al., 2015). A criticism of integrated pharmacological content is that students may become overwhelmed with the amount of content included within a particular course (Bhardwaj et al., 2015; Zellner et al., 2003). The alternative to an integrated curriculum is to offer students separate, stand-alone pharmacology courses.

Appendix B. Modified Kirkpatrick's Quality Assessment Model (1967)

Outcomes		Rating score
Level 1	Participation	1 point
	Learner feedback on the learning experience (organization, presentation, content, teaching materials, quality of instruction)	
Level 2a	Attitudes or perceptions	1.5 points
	Changes in attitudes towards intervention or simulation	
Level 2b	Knowledge and skills	1.5 points
	Knowledge: acquisition of concepts, procedures, or principles	
	Skills: acquisition of thinking or problem solving, psychomotor, or social skills	
Level 3	Behavioural change	2 points
	Transfer of learning to the workplace or willingness to apply new knowledge and skills	
Level 4a	Organization practice	3 points
	Wider changes in organization or delivery of care, attributable to educational program	
Level 4b	Patient benefits	3 points
	Improvement in health or well-being of patients as a direct result of educational program	

Appendix C. The modified Newcastle-Ottawa scale tool for measuring the quality of the included studies

Domain	MERSQI item	Score	Maximum score
Study design	Single group cross-sectional or post-test only	1	3
	Single group pretest and post-test	1.5	
	Nonrandomized, 2 groups	2	
	Randomized controlled trial	3	
Sampling	Institutions studied:		3
	1:	0.5	
	2:	1	
	3:	1.5	
	Response rate (%)		
	Not applicable		
	< 50 or not reported	0.5	
	50–74	1	
	75–100	1.5	
Type of data	Assessment by participants	1	3
	Objective measurement	3	

Validity of evaluation instrument	Internal structure		3
	Not applicable		
	Not reported	0	
	Reported	1	
	Content		
	Not applicable		
	Not reported	0	
	Reported	1	
	Relationships to other variables		
	Not applicable		
	Not reported	0	
	Reported	1	
Data analysis	Appropriateness of analysis		3
	Inappropriate for study design or type of data	0	
	Appropriate for study design and type of data	1	
	Complexity of analysis		
	Descriptive analysis only	1	
	Beyond descriptive analysis	2	
Outcomes/Kirkpatrick's outcomes	Satisfaction, attitudes, perceptions, opinions, general facts	1	3
	Knowledge, skills	1.5	
	Behaviours	2	
	Patient/health outcomes	3	
Total possible score			18

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