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The Confusion Between Intravenous Sodium Chloride and Potassium Chloride: A Potential Application for a Problem Based Learning (PBL) in Nursing Education to Minimize Medication Errors

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Sodium chloride and potassium chloride are two metal halides easily distinguishable by chemistry students. Nevertheless, it has been shown that the confusion between sodium chloride and potassium chloride is the underlaying cause of serious medical mistakes that may potentially culminate with the death of the patient. In the present literature review, a qualitative approach is used to examine relevant teaching practices, such as a problem base learning (PBL) approach that could be integrated in the undergraduate chemistry curriculum for nursing students to minimize the confusion between the two chemicals.

Graphical abstract

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1. Introduction

The present review analyzes practical aspects of how chemical education for the allied medical sciences may affect future professional performance of the students to which is directed. Chemistry constitutes an important component of the undergraduate curriculum for nursing students although is not a requirement for licensure, at least in the United States of America, and it is inconsistently taught throughout the different nursing schools [1]. Over time the chemistry departments of major universities developed a specific curriculum directed to students of nursing and the health sciences, sometimes referred as the allied medical sciences [2]. The curriculum directed to nursing students to students of the allied health sciences is less concerned with the aspects of chemistry related to the physical and mathematical interpretation of the matter; rather it is designed to highlight a wide array of topics related to the different aspects of the nursing profession [2].

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One of the most basic core competencies for the chemistry curriculum for nurses is chemical nomenclature. Nursing students are generally expected to be able to recognize, name, and distinguish chemical compounds by their formulas, their common or commercial names, or by the official nomenclature promulgated by the International Union of Pure and Applied Chemistry (IUPAC). Learning the chemical nomenclature may become a tedious task for the non-practitioner, as it involves catching up with years or development and evolution of both official and commercial names. Despite the tedious aspect of learning a clear and concise understanding of the chemical nomenclature provides the fundamentals for operating professionally [3]. In the specific: the ability to recognize the properties of different chemicals and to maintaining the ability to do so, over one's career spam will be examined in detail as it has been proven to be the demarcation line between life and death.

Potassium chloride (chemical symbol KCl) is a metal halide salt formed by the combination of potassium metal and chlorine ion in anoxic environment in a 1:1 stochiometric ratio. Potassium chloride is listed as one of the essential medicines of the World Health Organization (WHO) and it is available in different dosages to replenish patients' loss of electrolytes due to vomiting, diarrhea, or other loss of fluids. Potassium chloride, if administered in excess or incorrectly is also a lethal drug causing the hearth to stop [4]. Sodium chloride (chemical symbol NaCl) is a metal halide formed by the combination of sodium metal and chloride ion in a 1:1 stoichiometric ration. When in solution, sodium chloride becomes an electrolyte known for regulating the amount of water in the human body. Because of its central role in human physiology, sodium chloride is a very common drug dispensed in different pharmaceutical forms. Sodium Chloride is also referred as salt or table salt. Potassium chloride is often confused sodium chloride solutions, abundantly prescribed to maintain the patients' tone and body fluids.

Extensive research has analyzed the root cause of the confusion between potassium chloride and sodium chloride. Rodziewicz and Hipskind [5] and Harkanen, Vehviläinen-Julkunen, Murrels, Rafferty, and Franklyn [6] independently analyzed sources of medical errors in different contexts. Rodziewicz and Hipskind focused their analysis on the United States, while Harkanen, Vehvilainen-Julkunen, Murrels, Rafferty, and Franklyn analyzed the medical errors in the England and Wales. The study by Rodziewicz and Hipskind [5] focuses on the prevention of medical errors. In their analysis they researchers group medical errors in two types:

"*1. Errors of omission occur as a result of actions not taken. Examples are not strapping a patient into a wheelchair or not stabilizing a gurney prior to patient transfer.*

2. Errors of the commission occur as a result of the wrong action taken. Examples include administering a medication to which a patient has a known allergy or not labeling a laboratory specimen that is subsequently ascribed to the wrong patient."

Within these two broad types they identify several sub-types of errors including: surgical, diagnostic, medication, misconnections, faulty equipment, iatrogenic infections, falls, loss of records, and acute intervention. Mistakenly administer potassium chloride instead of sodium chloride would fall into the medication type of error under the classification of Rodziewicz and Hipskind [5].

Harkanen, Vehviläinen-Julkunen, Murrels, Rafferty, and Franklyn [6] analyze 517,384 medication errors, that took place in England and Wales in between 2006 and 2017, 229 of which led to the death of the patient. In their extensive review they include the confusion between normal saline and potassium chloride as one of the medication errors that caused the death of a patient, and they classify this error as related to blood and nutrition.

Both research groups indicate as a common and often lethal medical error the infusion of a concentrated solution of potassium chloride [5,6]. Additional studies that pointed out the confusion between the intravenous administration of sodium chloride and potassium chloride include a Swedish study reviewing 585 medication errors [7] and a cross-sectional study on Palestine nurses [8]. A different approach was taken by Cohen and Smetzer [9] that identified a potential reason of confusion between commercial names of sodium chloride solutions salts of RABEprazole for children (ACIPHEX SPRINKLE) and the one for adults (AcipHex delayed-release tablets). This last case, despite being interesting, is beyond the scope of the present study.

The problem, hence, is the easy confusion between sodium chloride and potassium chloride [4]. The problem is very relevant in current nursing practice since while a trained individual can easily recognize, even under pressure the difference between a common drug (NaCl) and one with potentially lethal side effects, a nurse lacking specific training may easily oversee the difference [10]. The extent of the problem is the combination of a lack of proper chemical foundations, along with difficulties in created by the high-pressure environment of a hospital has made it difficult to distinguish the two chemicals becoming a source of medical mistake [5,6]. Patients are impacted by the issue, because they eventually die if given the incorrect drug, or a drug with the incorrect dosage. Nurses are impacted too since the respective careers can be destroyed by an oversee such as confusing sodium chloride with potassium chloride. Existing literature acknowledges the lack of interest for nursing students in learning a discipline not directly related to the profession however, current literature does not address the problem by providing or proposing a solution to be implemented.

The present study seeks to fill the gap in the literature by providing the basis for a Problem Based Learning (PBL) approach for distinguishing sodium chloride with potassium chloride, which could help provide solutions to remedy the potential source of medical mistake. PBL is a student-centered pedagogical approach focused on the development of a process to solve a problem [11]. In a study program designed under the PBL approach learning is triggered by stimulation the learner to find the solution of a problem. The PBL approach does not focus much on the solution, rather to the process, and instructors are envisioned as facilitators guiding the students throughout the process. PBL curricula have been designed and implemented in different areas of teaching and learning including high school chemistry [12], chemical thermodynamics [13], nursing [14, 15, 16], and others [17].

The efficacy of a PBL approach for distinguishing a commonly prescribed drug (normal saline) from a potentially lethal one (potassium chloride) is currently unknown and, to the best knowledge of the writer, it has not been examined in any article published in peer reviewed journals. Because of the way the chemistry curriculum for nurses and the allied sciences professionals is structured, the analysis should be developed in the context of both pedagogy and andragogy since nursing students can come straight out of high-school, or adult learners looking for a career switch. Ultimately the

present study it may serve as a tool for many college and hospitals administrators to reorganize their curriculum for chemistry for the health sciences.

The present literature review addresses the following research questions:

Research Question 1: What is the consensus in the current literature examining the link between the schooling of nursing students and the prevention of medical mistakes?

Research Question 2: What specific steps can be implemented to prevent medical mistakes related to the use of a drug?

Research Question 3: What are the findings in the field of medical pedagogy and andragogy that can be used to provide actionable recommendations to prevent the confusion between sodium chloride and potassium chloride?

For the purpose of the analysis developed for this study, it will be assumed that the allied health professions are professions within the healthcare field other than dentistry, nursing, medicine, and pharmacy. For andragogy it will be understood that the term refers to methods and principles in adult education [18]. Normal Saline, also known as saline, or saline solution, is a mixture of sodium chloride and water that has a wide range of applications in medicine [19]. Normal saline has a mass percentage concentration of sodium chloride in water of 0.9% to make it isotonic with human blood. Nursing is a profession within the healthcare sector dedicated to carry on the practical aspects of medical care.

2. Material and Methods

The present investigation has been conducted as a qualitative literature review by examining scholarly articles published in peer-reviewed journals rom medical databases within the past five years, and the references quoted therein. A qualitative literature review is one of the accepted methodologies to conduct scholarly research in the social sciences and educational [20], and it has been widely applied to analyze different aspects of nursing education [21].

The methodology will be consistent with the seven steps approach outlined by Onwuegbuzie and Frels [22]. According to Onwuegbuzie and Frels there are seven steps necessary to conduct a sound literature review including:

1. exploring beliefs and topics,
2. initiating the search,
3. storing and organizing the information properly,
4. selecting and deselecting information,
5. expanding the search by using secondary data,
6. synthesizing and analyzing the information with the ultimate goal of providing a coherent interpretation, and
7. delivering or communicating the outcomes of the review [22].

The present literature review was designed to further research in the field of nursing and medical education and in the field of suppression of medical mistakes by developing the answers to the three research questions. A total of 27 articles were identified to be relevant to the three research questions and were therefore analyzed accordingly.

In their 2015 book, Onwuegbuzie and Frels improved over the prior art by not only pointing out that a literature review it is a research method but also that it is a viable tool to highlight gaps in the literature that can be used to identify shortfalls that may not otherwise have been evident.

The search was performed using the following keywords: medical error potassium, medical mistakes potassium, potassium chloride, sodium chloride, mistake sodium chloride, mistake potassium chloride, error sodium chloride, error potassium chloride. The articles were then be screened for relevance and only the ones that match the topic of the study will be selected. The search was deemed conclusive after all the articles returned by the query in the different databases were be screened and considered.

During the literature review, journal articles published in peer-reviewed journals were identified via qualitative research methods. Journal articles published in peer-reviewed journals over the last five years (2015-2020) will be searched in the following data bases of scholarly research:

Center for Diseases Control and Prevention (CDC) Stack,

Google Scholar,

MedPix,

National Institute of Health database (nih.gov),

National Center for Health Statistics,

PubMed, and

Semantic Scholar.

These seven databases were selected because of their relevancy in the educational and medical fields, and because of their enhanced accessibility by professionals in these fields.

The selected journal articles have been summarized and organized into a document providing theoretical basis supporting a PBL approach to teach chemistry in undergraduate nursing schools. A qualitative research study, such as the one developed herein, can answer the why and how questions and get to the root of what the respondents really think about a topic [24]. The data obtained can be informative and influential to nursing programs administrators around the country.

The assumptions on which the present literature review is based are that a comprehensive search of the literature could be done by accessing online databases as described in the literature search strategy. Literature not available online would not have been considered.

The scope of the present literature review has been limited to articles published in peer-reviewed journals within the past five years and the references contained therein. Therefore, it is possible that an older body of literature may not have been considered.

3. Results and Discussion

Research Question 1: What is the consensus in the current literature examining the link between the schooling of nursing students and the prevention of medical mistakes?

Lobaugh, Martin, Schleelein, Tyler, and Litman [25] in a study examining the intravenous administration of drugs between the year 2010 and 2016, reported that 97% of the

medication errors during an anesthesia procedure were preventable. In their analysis, Lobaugh et al. classified the medication errors according to six different criteria including (1) medication category; (2) error type by phase of administration; (3) bolus of infusion error; (4) provider type and associated level of training; (5) harm; and (6) perceived preventability. While most medication errors were found to cause harm to the patient, their preventability was found to be related to the level of training of the provider. Samundeeswari and Muthamilsevi [26] examined the relationship between nurses' knowledge and the prevention of medical mistakes. Strikingly Samundeeswari and Muthamilsevi estimated that every year between 44,000 and 98,000 individuals die in hospitals worldwide due to medication errors. In a study of 50 staff nurses they also identified a statistically significant negative correlation between the level of education and medication errors. In their analysis Samundeeswari and Muthamilsevi pointed out that medication errors arising from lack of knowledge can be addressed by additional training and education, but there are also errors related to the lack of practice in a specific area that are more difficult to detect. These medication errors were named memory-based errors and were more common among nurses changing field of department. Strategies such as continuing education programs were suggested as a possible way to prevent memory-based medication errors. The consensus of the literature is that there is an inverse correlation between the level of schooling and the chances of committing a mistake such as exchanging sodium chloride for potassium chloride. As an additional tag on the topic, it has also been argued that nurses switching from one specialty to another one without being properly re-trained are more likely to incur in medical mistakes.

Research Question 2: What specific steps can be implemented to prevent medical mistakes related to the use of a drug?

While there is no agreement on the mandatory inclusion of chemistry in undergraduate nursing curriculum, it could be argued that proper teaching of chemical nomenclature should at least in principle mitigate the issue. One additional reason of concern is the lack of interest in a seemingly rather boring topic such as chemical nomenclature for nursing students makes it difficult to successfully implement best practices to distinguish a commonly prescribed drug (normal saline) from a potentially lethal one (potassium chloride) [4,5]. The literature related to modern approaches of teaching chemistry for nursing students clearly shows the increase in popularity of a PBL approach in recent years due to the high level of interactivity and livelihood of the approach [15, 27; 28]. Despite the evidence of positive outcomes showing the effectiveness of a PBL approach in nursing education, there are difficulties in developing a comprehensive chemistry curriculum for nursing students based on a PBL approach.

Two such themes found in literature reviews of the topic are: one is the long term, and well known, struggle on the role of instructor in a nursing class [29], the other one is: chemistry, as a discipline, is not always recognized as one of the fundamental core competencies for the nursing profession [29]. The theoretical framework for the present literature review is constructivism [30]. In the specific context of teaching the practical applications of chemical nomenclature such as distinguishing a commonly prescribed drug (normal saline) from a potentially lethal one (potassium chloride), the literature highlights one significant gap: i.e. practical applications of the notions taught and learned in the classroom are often not developed in a PBL context. The present literature review examines different aspects of introducing PBL exercises in an undergraduate chemistry curriculum for nursing students [27,28].

In the United States of America to teach college level classes an instructor must generally hold at least a master's degree in the specific discipline he or she teaches. To qualify as a nurse an aspirant only needs to earn an associate degree in nursing and pass a state mandated qualifying examination. The requirement for a qualified instructor at a master's level may be lowered down to a bachelor's degree holder [31, 32]. In a qualitative analysis of the perception of important chemistry concepts introduced to nursing students, Brown, Barbera, and Hyslop [33] observed a substantial difference in teaching expectations. For example, for a professionally trained chemist it is common to be aware of the different nomenclature of chemical compounds, including the commercial nomenclature [34], the nomenclature of the International Union of Pure and Applied Chemistry (IUPAC) [35], and the common nomenclature [36]. In other countries the discrepancy between the qualifications of a chemistry instructor and the qualifications of a chemistry instructor for nurses are even more dramatic. Rizvi [29] reported people with different backgrounds such as Doctor of Philosophy, master of philosophy, masters in science, bachelor of medicine, bachelor of surgery, bachelors in engineering, doctor of pharmacy and registered nurse with a master's degree were found to be qualified to teach chemistry to nursing students in Pakistan.

A separate issue to address when examining the need for a chemistry undergraduate curriculum for nursing students is whether a separate chemistry course is really needed or not. In absence of a clear guidance from state boards usually chemistry is taught in nursing school during the first two years [2]. On the other hand, the teaching of chemistry for nursing students is not always consistent: some schools requiring a laboratory component, other not requiring it [1]. Ma points out how the lack of a clear standard for the science foundations of nurses creates a lack of technical competency difficult to fill out later [37].

In support for a solid understanding of basic chemical concepts such as nomenclature, as applied to the nursing profession is a study by Miller, Haddad and Phillips [10] describing different educational strategies to minimize the potential for medical mistakes due to lack of technical competency. In their literature review study Miller, Haddad and Phillips highlight how creating a culture of safety and awareness since the undergraduate years can help preventing medical mistakes [10].

While the call for a solid understanding of basic sciences for nursing students is clear, bridging the gap to real world applications has proven to be a challenge [33]. In a literature review study of 200 articles published in peer-reviewed journals Clark, Raffray, Hendricks and Gragnon did not identify chemistry as one of the core competencies for nursing students [38]. Chemistry may not necessary be a central science for the nursing profession as exemplified by the statements of nursing students reported by Boddey and de Berg [39]:

"*Phebe: I know it (chemistry) is background knowledge but when are we going to use this on the ward and how much chemistry we are going to remember once we start working as nurses.*

Paula: I think some of the basic ideas of chemistry are important, but I don't know if the level of chemistry taught is really necessary"

Seeing chemistry somewhat a separate discipline not necessary for the professional nurse may contributing cause of an entire class of medical mistakes [10]. Still there is no agreement in the literature as to the importance of chemistry as a core competency for professional nurses [33].

In view of the extensive review of the background literature above steps to prevent the misuse of potassium chloride in a hospital settings instead of normal saline include: developing an appropriate chemistry curriculum for undergraduate nursing students, sensitizing faculty and administrators over the need of focusing their attention to the solution of practical application or chemistry, and the introduction of PBL experiences that can associate the idea that extra attention is needed when administering potassium chloride with the long term teaching of chemical nomenclature.

Research Question 3: What are the findings in the field of medical pedagogy and andragogy that can be used to provide actionable recommendations to prevent the confusion between sodium chloride and potassium chloride?

Andragogy is a comprehensive approach to adult learning articulated in six broad assumptions: the need to know, a critical analysis of the perception of self, the role played by the learners' past experiences, the readiness to learn, the orientation to learn, and the personal motivation [40]. In critical situations, such as a life-threatening emergency or a war action, there is not time to articulate and justify a decision that is often imposed as an order [41]. The proper execution of an order or direction often relies on the mechanical understanding of the sequences of steps to be performed by the subordinate. This is often insured by years of training and permanent follow up in the form of musters, drills, briefings, debriefings, and periodic qualifications [42]. A similar approach, when applicable, to patient safety could potentially be applied to the prevention of medical errors, in the specific to the prevention of medication mistakes where a wrong drug is used in an emergency context.

The literature analyzed does not address the specific application of andragogy or PBL to the prevention of medication errors due to the confusion between sodium chloride and potassium chloride, rather examine the greater issue of using PBL as a pedagogical approach for the natural sciences in the undergraduate curriculum for nursing students [43, 44]. A great deal of attention has been placed on the identification of preventable medication errors, on the other hand such a large body of literature encompassing the problem relation between sodium chloride and potassium chloride has not led to the development of teaching strategies for its prevention. Therefore, there is the need in the art for the development of such educational strategies under the light of the current literature.

A PBL approach for teaching specific aspects of chemical nomenclature may contribute to increase nursing students' self confidence in chemistry related tasks and eventually to minimize or suppress chemical errors. Despite the benefits of an enriched chemistry curriculum in undergraduate chemistry for nursing students and students of the allied health sciences, the idea of a properly planned curriculum enriched with PBL experiences, often struggles to take off. The problem and research questions are aligned, and the literature review will provide an analysis of the difficulties in promoting a PBL approach for important aspects of chemistry classes for nursing students.

4. Conclusions

Medication errors constitute a class of medical mistakes considered to be fully preventable [5, 6]. Reeve and Allison made a point in highlighting that the confusion of sodium chloride with potassium chloride is often a lethal, but preventable, medication error [4].

With respect of confusing one chemical with the other one, several explanations have been proposed, for a novice nurse, is lack of knowledge or understanding of the critical difference between the two compounds may just be the underlying cause of the error. For a more experienced nurse lack of memory is more likely to play a role especially if the nurse usually practices in a different field [26].

By reviewing scholarly articles published in peer-reviewed journal available online in medical databases it emerges that possible steps to prevent the confusion between sodium chloride and potassium chloride include developing an appropriate chemistry curriculum for undergraduate nursing students, sensitizing faculty and administrators over the need of focusing their attention to the solution of practical application or chemistry, and the introduction of PBL experiences that can associate the idea that extra attention is needed when administering potassium chloride with the long term teaching of chemical nomenclature. For example, Miller Haddad and Phillips [10] described different educational strategies to minimize the potential for medical mistakes due to lack of technical competency including the introduction of simulations, online learning, and the analysis of case studies. Miller, Haddad and Phillips point out that simulations are the most frequently used method used to master nurses' sensibility with respect to safety [10]. In their conclusion paragraph they advocate for a reform of the nursing curriculum to include interactive learning techniques such as simulation in the core classes of nursing degrees. This conclusion seems to be in line with the idea that by challenging students to develop a solution to a problem may push them to develop their own strategies in line with the general theory and that these strategies may eventually root into students' permanent memory.

With respect to applying andragogy to teaching and learning in the nursing filed, the needs come into place as most nursing students enter the profession or later in life or need to be periodically retrained due to the changes in technological, scientific, and medical findings [46, 47]. The introduction of evidence-based research provides the factual basis for introducing those changes [48]. Learning techniques developed for military and emergency context may provide a way of addressing some of the issues highlighted above by integrating appropriate PBL experiences into an andragogy context [40, 41], although little effort has been put into developing educational solutions that specifically approach the seemingly unresolved confusion between potassium chloride and sodium chloride.

These conclusions were reached after analyzing the current (<5 y.o.) literature in peer-reviewed medical journals, mainly in English language, available online and the references contained therein. Other information may have been developed, but not considered because of these limitations

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