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ORIGINAL RESEARCH

# Efficacy of a context-based learning approach to improve the learning of concentration units calculation among medical students

*Efectividad de una propuesta de aprendizaje basada en el contexto para mejorar el aprendizaje del cálculo de concentraciones en estudiantes de medicina*

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## Abstract

**Introduction:** Medical students need to learn and acquire skills to calculate the concentration of chemical solutions in order to be able to use them properly during their professional life.
**Objective:** To evaluate the efficacy of a learning resource designed using the context-based learning (CBL) approach to improve the skills required for solution concentration unit calculation among first-semester medical students of a public university.
**Materials and methods:** Design-based research conducted in three phases: design, intervention, and evaluation. In the first phase, the *Solutions with Empathy* learning resource was developed. The intervention was carried out during the second semester of 2020 with first-semester students of the Medicine program offered by the Universidad Nacional de Colombia and enrolled in the course Basic Chemistry for Health Sciences. An experimental study in which 66 volunteers took a knowledge questionnaire (pretest) and were randomly distributed into two groups was conducted. The experimental group (n=30) used the resource and then completed the post-test knowledge questionnaire, while the control group (n=36) did the opposite. Subsequently, 120 students took the regular course test. Bivariate analyses were performed to evaluate differences in test performance between the two groups and in the regular course test between resource users and non-users. Finally, to assess their perception on the resource, a questionnaire designed for this purpose was answered by 34 students, and the comments made by 116 professors/students during the forum of an academic outreach event were analyzed.
**Results:** Statically significant differences were observed in the mean scores obtained in the post-test knowledge questionnaire in favor of the experimental group ($p$=0.003) and in the regular course test in favor of those who used the resource ($p$=0.041). The resource was positively rated by students and professors.
**Conclusion:** The CBL approach of the learning resource evaluated here favored the learning of concentration unit calculation among the students who used it, increasing their motivation on the topic.

## Resumen

**Introducción.** Los estudiantes de medicina necesitan aprender y adquirir destreza en el cálculo de la concentración de las soluciones químicas para poder usarlas adecuadamente durante su vida profesional.
**Objetivo.** Evaluar la efectividad de un recurso didáctico diseñado con el enfoque de aprendizaje basado en el contexto (CBL) para mejorar el aprendizaje del cálculo de las unidades de concentración de las soluciones químicas en estudiantes de primer semestre de medicina de una universidad pública.
**Materiales y métodos.** Investigación basada en el diseño realizada en tres fases: diseño, intervención y evaluación. En la primera fase se elaboró el recurso didáctico *Soluciones con empatía.* La intervención se realizó durante el segundo semestre de 2020 con los estudiantes del programa de Medicina de la Universidad Nacional de Colombia inscritos en la asignatura Química Básica para Ciencias de la Salud. Se realizó un estudio experimental en el que 66 estudiantes contestaron una prueba de conocimientos pretest de forma voluntaria y fueron distribuidos aleatoriamente en dos grupos. El grupo experimental (n=30) usó el recurso y después presentó la prueba de conocimientos postest, mientras que el grupo control (n=36) hizo lo contrario. Posteriormente, 120 estudiantes presentaron el examen regular de la asignatura. Se realizaron análisis bivariados para evaluar diferencias en el desempeño en las pruebas entre ambos grupos y en el examen regular de la materia entre aquellos que usaron el recurso y aquellos que no. Finalmente, para evaluar la percepción sobre el recurso, se diseñó un cuestionario que fue respondido por 34 estudiantes, y se analizaron los comentarios de 116 docentes/estudiantes en el foro de un evento académico de divulgación.
**Resultados.** Se observaron diferencias estadísticamente significativas en la puntuación promedio de la prueba de conocimientos postest a favor del grupo experimental ($p$=0.003) y en el examen regular de la asignatura a favor de quienes usaron el recurso ($p$=0.041). El recurso fue valorado positivamente por estudiantes y profesores.
**Conclusión.** El enfoque CBL del recurso didáctico aquí evaluado favoreció el aprendizaje del cálculo de las unidades de concentración en quienes lo usaron, aumentado su motivación por el tema.

## Introduction

During their first year of undergraduate studies, medical students learn basic chemistry concepts that are fundamental to their future practice. The importance of this matter lies in the fact that, for example, learning to correctly calculate the different ways of expressing the concentration of chemical solutions is key for the proper prescription and administration of drugs and for clinical decision making based on the quantitative interpretation of laboratory test results, since any error in calculation can lead to irreversible consequences.[1,2] Therefore, chemistry professors often ask medical students to complete repetitive exercises to calculate the concentration of solutions in a mechanical and memory-oriented manner, until they master the subject, although several studies have demonstrated that this strategy discourages students' motivation to learn and does not promote meaningful learning.[3,4]

Other factors that discourage motivation for studying chemistry among first-semester students, regardless of their academic program, include the intrinsic difficulty of the contents of the discipline,[5] the dissociation between theory and practice,[6] and their perceived lack of applicability of the contents to their profession.[7]

Motivation for study is a critical element in the learning process of experimental sciences influencing academic performance.[8] In programs such as medicine, this aspect is especially relevant because students need to be highly motivated to continue studying a program that entails full commitment and dedication to work.[9]

In order to promote motivation and interest in learning experimental sciences, the context-based learning (CBL) strategy has been implemented in recent years. This approach applies concepts to real life situations familiar to students[10] in order to promote meaningful learning and the development of problem-solving skills[11,12] and metacognition.[13] This approach enables students to learn chemistry concepts and apply them in different contexts,[14] in addition to making them feel that what they have learned is relevant to their professional lives while enjoying the learning process.[15]

The contextualization of contents and assignments favors structured learning without distracting students; moreover, it fosters the development of critical thinking skills beyond what has been studied, which is why the design of appropriate contexts is especially relevant in CBL.[16] The context approach in the teaching of experimental sciences for different disciplines is focused on the definition and solution of problems that are commonplace in each field of knowledge. In medicine, for example, the ethical dilemmas of medical practice serve as scenarios that contribute to the development of critical thinking.[17]

On the other hand, information and communication technologies (ICT) make it possible to create simulated contexts in digital environments that help to give meaning to the problems to be solved, as these technologies facilitate the design of educational experiences with the introduction of new digital narratives through visual, auditory, and/or sensory languages.[18] University students recognize the enormous potential of ICTs to support their learning and improve their academic performance,[19] so they should be considered as part of any proposal to improve teaching and learning processes at the university.

In view of the foregoing, the objective of the present study was to evaluate the efficacy of a learning resource designed using the CBL approach to improve the acquisition of skills for solution concentration unit calculation among first-semester medical students at a public university in Colombia.

## Materials and methods

### Study type

Design-based research developed in three phases: design, intervention, and evaluation. This type of research, oriented towards pedagogical innovation, connects educational theory, research and practice with the purpose of transforming or improving a problematic situation through the introduction of a new element, including classroom programs, teaching strategies, educational resources, among others.[20]

### Study population and sample

The research was conducted with two study populations:

*Population 1:* Comprising 123 first-semester students of the Medical program offered at the Universidad Nacional de Colombia (UNAL) enrolled in the course Basic Chemistry for Health Sciences (BCHS) in the second academic term of 2020, with the following characteristics: 71 men and 52 women between 15 and 47 years old with an average age of 20.20 years. Information obtained from the university's Academic Information System (Sistema de Información Académica, SIA by its acronym in Spanish) was used to characterize this population.

*Population 2:* Comprising 237 members of the UNAL (132 women and 105 men) from exact sciences or health sciences programs who registered in the National Congress of Pedagogical Innovation Initiatives held at the UNAL in February 2021. This population was made up of 90 professors (37.97%), 112 students (47.26%) and 35 graduates (14.77%) from five UNAL campuses: 4 from the Amazon area (1.69%), 189 from Bogotá (79.74%), 14 from Manizales (5.91%), 27 from Medellín (11.39%), and 3 from the Orinoquia region (1.27%). This population was characterized using information from the registration database obtained for the Congress by the National Directorate of Academic Innovation (Dirección Nacional de Innovación Académica - DNIA by its acronym in Spanish) of the university.

The sampling design for population 1 was multistage. In the first stage, 2 primary sampling units (PSU) were generated; PSU 1 consisted of 66 students (53.66% of population 1) who agreed to voluntarily participate in the intervention and use the teaching resource, while PSU 2 comprised the 120 students (97.56% of population 1) who took the regular test of the course. In the second stage, a secondary sampling unit (SSU) was generated, consisting of 34 PSU 1 students (51.51%) who anonymously completed a questionnaire on their perception of the resource after using it (Table 1).

In the case of population 2, the sample consisted of the 116 participants (48.95%) who voluntarily commented on the learning resource *Solutions with Empathy* during the congress forum (Table 1).

In all cases, the sampling was non-probabilistic, casual or incidental, with the exception of the configuration of the control and experimental groups for PSU 1, which was randomized.

**Table 1.** Research populations and samples.

| Process | Population | Sample | Stage |
|---|---|---|---|
| Determination of resource impact | Population 1: 123 students of Basic Chemistry for Health Sciences | PSU 1: 66 volunteer students (33 female and 33 male) randomly divided into an experimental group (n=30) and a control group (n=36) with an experimental:control ratio of 1:1.2 | 1 |
| | | PSU 2: 120 students (50 women and 70 men) who took the exam, of whom 63 used the resource | 1 |
| Perception on the resource | PSU 1: 66 students who used the resource | SSU 1: 34 student volunteers who completed the perception questionnaire anonymously | 2 |
| | Population 2: 237 participants registered for the 2021 National Congress of Pedagogical Innovation Initiatives | 116 members of the Universidad Nacional de Colombia (66 women and 50 men) who participated in the forum on the *Solutions with Empathy* resource during the congress and submitted their comments on it. 43 professors, 58 students, and 15 graduates were included. | - |

PSU: primary sampling units; SSU: secondary sampling units.
Source: Own elaboration.

## Instruments

### *Teaching resource*

*Solutions with empathy* is an interactive learning resource that simulates the daily situations experienced by four characters related to alcohol consumption (liquid solutions) and its impact on the body (available at https://view.genial.ly/5f2e106620c4eb0d81b13a31). Its name refers to the course's disciplinary content (homogeneous mixtures or solutions) as well as the fact that medical students must learn to solve moral dilemmas during consultations by not only calculating solution concentrations but also acting empathetically. Empathy is a fundamental aspect of the patient-physician relationship and is necessary to deliver the appropriate care that the patient requires.[21]

The resource was coded to offer a free navigation system, so that each user could explore the situations in any order and with no time limit. Students could complete the assignments and deal with the ethical dilemmas summarized in Table 2.

**Table 2.** Characters, situations, assignments and ethical dilemmas presented in the resource *Solutions with empathy*.

| Character |  **Responsible woman disappointed in love** |  **A cheerful man and an enthusiastic dancer** |  **Successful workaholic young woman** |  **Mature but nice** |
|---|---|---|---|---|
| **Situation** | Heartbroken, she drinks a few beers and feels too sick to go to work | After having a few glasses of wine at a party he feels he is going to die | While celebrating his birthday at the office, he drinks a glass of gin and loses his driver's license | After a few drinks, he rides a bicycle and is involved in a traffic accident |
| **Questions about solutions** | Calculate the mL of alcohol consumed based on % Vol<br>Calculate molar blood alcohol concentration | Calculate the mL of alcohol consumed based on % Vol<br>Calculate the amount of lethal alcohol according to weight | Calculate ethanol concentration in blood expressed in g ethanol/dL of blood<br>Calculate the length of license suspension based on alcohol content and Colombian regulations | Associate molar blood alcohol concentration with relative accident risk<br>Calculate the degree of intoxication based on the concentration in g/dL and Colombian regulations |
| **Ethical dilemma** | Would you issue a medical leave of absence for a woman disappointed in love?? | Would you advise the dancer to gain weight to avoid death from excessive drinking? | Would you help the successful young workaholic by certifying that she is fit to drive? | Would you alter the result of the patient's breathalyzer test so that the insurance will assume the costs of the accident? |

Source: Own elaboration.

To avoid making comparisons with real individuals, characters are not given names, but rather are identified with statements that provide information about their social and/or emotional characteristics. This was done because physician must pay attention to these aspects as well as to physical signs, in order to show empathy during the consultation and come closer to a better diagnosis that will allow helping the patient adequately.[21]

Each task receives feedback, and each dilemma offers a reflection from a medical ethics perspective. Thus, the students themselves find answers to the questions of why and for what purpose they need to learn to calculate the concentration of the solutions correctly, which constitutes a metacognitive strategy that favors the learning process.[22]

### *Data collection instruments*

The instruments for data collection were designed ad hoc and were administered through Google Forms. They are described below.

A differentiated knowledge test was designed for the pretest (Annex 1) and posttest (Annex 2) moments, including multiple choice questions with 4 options and only one correct answer. These questions are about the determination of the amount of solute, the transformation of concentration units, and the inference of results based on standard scales. The knowledge test had 10 questions in the pretest and 15 in the posttest. The data of both tests are different to prevent them from memorizing the correct answers.

Another instrument used was the regular course test, which, among its 50 questions, includes 7 items on concentration units that are not the same as those of the differentiated knowledge tests, although they follow the same format.

The resource perception questionnaire (Annex 3) was made up of 10 statements evaluated on a Likert scale from 1 to 5 (1: Strongly disagree; 2: Partially disagree; 3: Neither agree nor disagree; 4: Partially agree, and 5: Strongly agree) plus an optional open-ended question in which suggestions about the resource could be made. The statements were designed to address two dimensions: learning and technological development. The first included 5 sentences relating the use of the resource with aspects of the CBL approach such as context, meaningful learning, motivation, and applicability in everyday practice. The second included 5 sentences on the development of the teaching tool related to navigation, design, and the material and human resources required for its development.

Finally, a forum was developed in the virtual classroom of the National Congress of Pedagogical Innovation Initiatives, which was available from February 16 to March 30, 2021, and in which participants were asked to evaluate, voluntarily, the resource *Solutions with empathy*.

## Procedures

### *Design stage*

In this first phase, the BCHS professors who participated in the research shared their knowledge as a team and developed the learning resource *Solutions with Empathy* through Genially,[23] an online tool for creating interactive and animated educational content.

### *Intervention stage*

The pedagogical intervention was carried out through an experimental design of 2 randomized groups in the BCHS virtual classroom (Figure 1). At the end of the regular activities on the subject scheduled in the course, students were invited to participate in an additional

pedagogical exercise. Hence, the pretest knowledge test was administered to the 92 volunteers who agreed to participate. Two weeks later, these students were randomly distributed into 2 groups with an equal number of individuals in order to reduce selection bias due to incidental sampling, and the virtual classroom was organized so that group 1 (experimental) would use the resource and then complete the posttest knowledge test, while group 2 (control) would first complete the posttest knowledge test and then use the resource. The activities were completed by 66 students (PSU 1): 30 from group 1 and 36 from group 2.

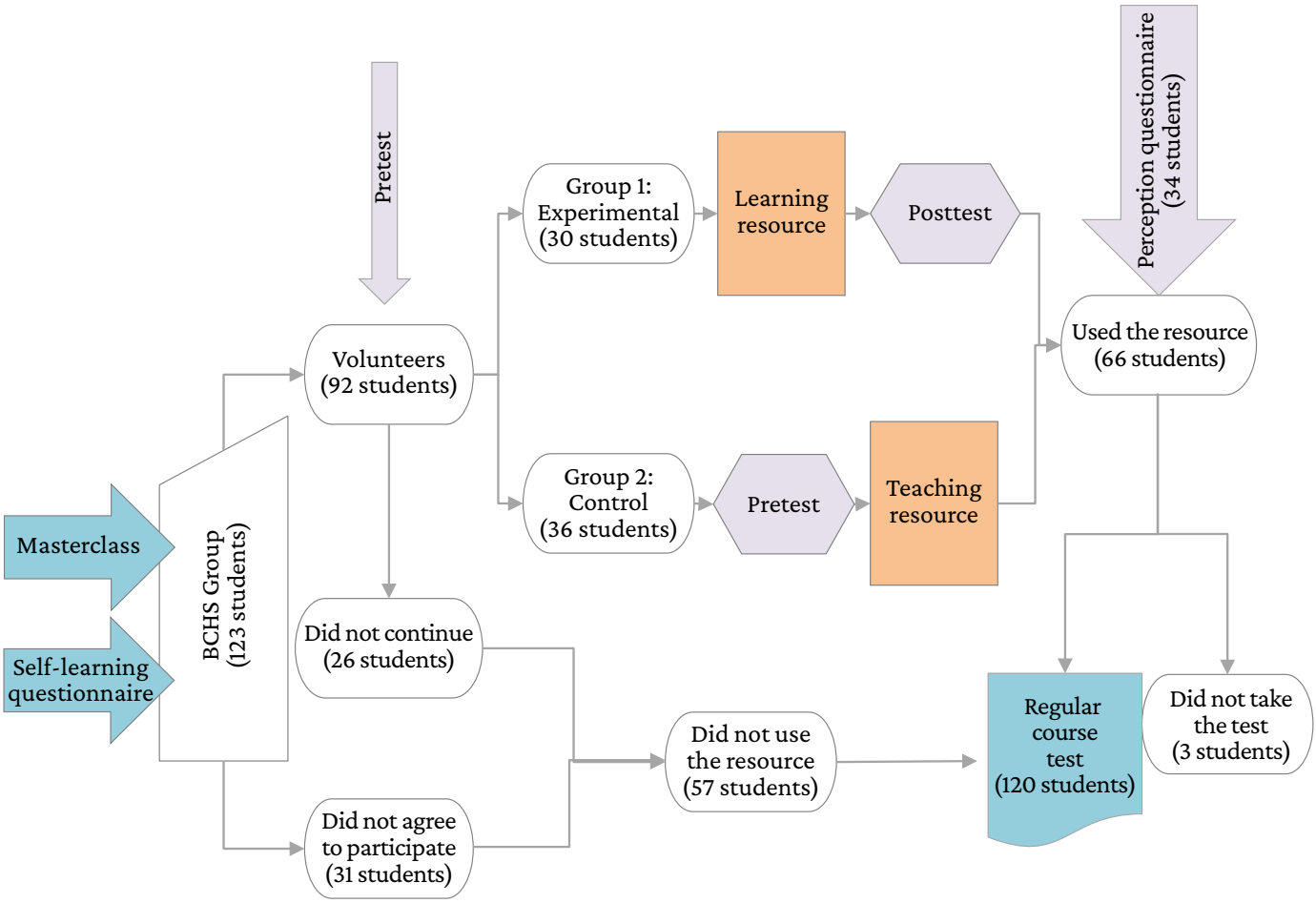


**Figure 1.** Diagram of the pedagogical intervention.
BCHS: Basic Chemistry for Health Sciences course.
Source: Own elaboration.

In order to know the perception of the users of the resource, a questionnaire was administered and answered anonymously by 34 of the volunteers (SSU 1). One week later, 120 students took the regular course test (PSU 2), and of these, 63 used the teaching resource (the design for this variable was quasi-experimental).

### *Evaluation stage*

In this stage, the impact of the resource was assessed by means of a statistical analysis of the results of both the knowledge tests and the regular course test. Quantitative and qualitative analyses of the results obtained with the perception questionnaire and a qualitative analysis of the comments posted in the congress forum were carried out.

## Data analysis

Quantitative data were automatically entered in the Google spreadsheets associated with the data collection forms. The data were processed and analyzed using SPSS v24. Data are described using absolute and relative frequencies (percentage of correct answers and/or responses in the different questionnaires and tests) for categorical variables and means and standard deviations for quantitative variables.

Regarding inferential statistics, bivariate analyses were performed to evaluate the differences in student performance between groups (pretest and posttest knowledge tests) and in performance on the regular course test between students who used the resource and those who did not. This was done using the nonparametric Mann-Whitney U test since the sample sizes were too small to obtain reliable results with parametric statistics taking into account a significance level of $p<0.05$ with a confidence interval of 95%.[24] Moreover, effect size (ES) was determined according to the following categories: low: <0.2, medium: 0.2-8, and high: >0.8. Analyses were performed for the entire sample and for men and women.

Qualitative data were processed using the Nvivo V.1.7.1 software. Classification into categories and subcategories was carried out following an inductive process. The analysis of the responses to the open-ended question of the perception questionnaire led to the following categories: New topics, More cases/characters, Better design, and More dissemination. Comments made at the congress forum were classified into the following categories: Clinical and Ethical Context, Technological Development, Empathy, Suggestions, and Questions.

## Ethical considerations

The study was approved by the National Directorate of Academic Innovation, which, through an institutional ethics committee, verified that all the ethical requirements were fulfilled, as stated in Minutes DNIA-075-2020 of June 10, 2020. In addition, the study was conducted at all times under the principles of truthfulness, fidelity, reciprocity and respect for autonomy, while respecting the dignity and protection of rights, as well as the well-being of the participants, who, prior to their inclusion in the study, were informed of the purpose of the research and signed the respective informed consent form.

Likewise, the study followed the ethical principles for biomedical research on human subjects established in the Declaration of Helsinki[25] and the scientific, technical and administrative standards for health research contained in Resolution 8430 of 1993 issued by the Colombian Ministry of Health.[26] Personal data were handled according to the UNAL's policies and confidentiality was preserved at all times.

# Results

The efficacy of the learning resource *Solutions with empathy* for improving the learning of solution concentration units calculation was evaluated by analyzing the results of the knowledge tests (pretest and posttest) and the regular course test, as well as from the perception that both the students who participated and the attendees at the congress forum had of their own learning after using the resource.

## Knowledge test

The difference in the mean score of the pretest knowledge test between the experimental group (7.97/10) and the control group (7.33/10) was not statically significant ($p$=0.46). After using the resource, the mean score on the posttest knowledge test of the experimental group (8.68/10) increased in greater proportion compared to the control group (7.47/10), the difference between the two groups became statically significant ($p$=0.003), and the ES was high (0.80), as seen in Figure 2.

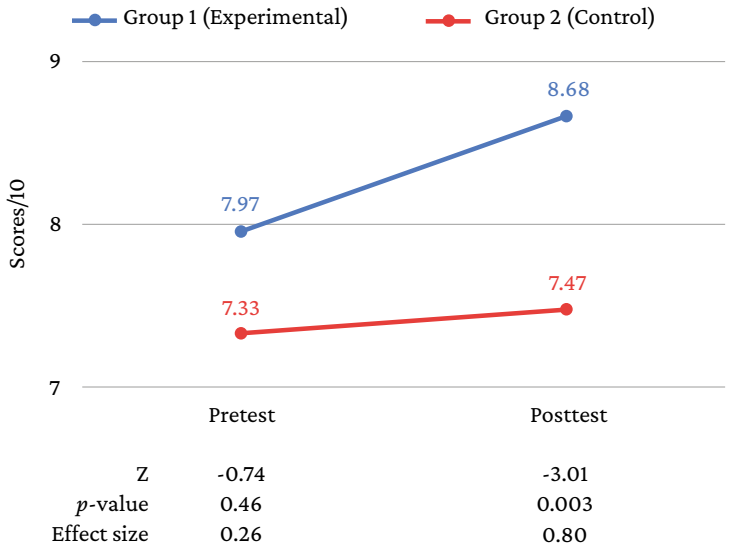


**Figure 2.** Pretest and posttest knowledge test scores and Mann-Whitney U test result and effect size for crossover of scores between the control and experimental groups of the posttest.
ES: effect size; Z: statistical value of the normal curve.
Source: Own elaboration.

When performing the analysis by sex (Table 3), a significant difference ($p$=0.008) in the mean posttest knowledge test score between the experimental and control groups was observed in women, with a high ES (1.07). However, this difference was not statically significant in men ($p$=0.13) despite the fact that the ES was medium (0.49). An increase in the mean scores of the posttest knowledge test was observed for both men and women in the experimental group compared to the mean scores obtained in the pretest.

**Table 3.** Pretest and posttest knowledge test scores and Mann-Whitney U test result and effect size for crossover of scores between control and experimental group of the posttest test as a function of sex.

| Sex | Test | Group | n | Mean/10 | Standard deviation | Z | $p$-value | ES |
|---|---|---|---|---|---|---|---|---|
| Female | Pre | 1: Experimental | 14 | 7.93 | 2.30 | -0.56 | 0.57 | 0.27 |
| | | 2: Control | 19 | 7.21 | 2.92 | | | |
| | Post | 1: Experimental | 14 | 8.75 | 1.10 | -2.65 | 0.008 | 1.07 |
| | | 2: Control | 19 | 7.05 | 1.87 | | | |
| Male | Pre | 1: Experimental | 16 | 8.00 | 1.93 | -0.41 | 0.68 | 0.23 |
| | | 2: Control | 17 | 7.47 | 2.50 | | | |
| | Post | 1: Experimental | 16 | 8.61 | 1.21 | -1.51 | 0.13 | 0.49 |
| | | 2: Control | 17 | 7.93 | 1.56 | | | |

ES: effect size. Z: statistical value of the normal curve.
Source: Own elaboration.

## Regular test

Concerning the regular test, users of the resource (n=63) obtained a higher average percentage of correct answers in the questions on concentration units (Table 4), and the difference with non-users of the resource was statically significant ($p$=0.041), with a medium ES (0.42). When analyzed by sex, the mean percentage of correct answers was higher in men and the difference was statically significant for men ($p$=0.031), with a medium ES (0.61), but not for women ($p$=0.515), for whom the ES was low (0.19).

**Table 4.** Regular test scores and Mann-Whitney U test result and effect size for crossover of scores between users and non-users of the resource.

| Sex | Resource use | n | Mean (% of correct answers) | Deviation | Z | $p$-value | ES |
|---|---|---|---|---|---|---|---|
| Both | Yes | 63 | 73.68% | 18.00 | -2.04 | 0.041 | 0.42 |
| | No | 57 | 65.16% | 22.73 | | | |
| Female | Yes | 31 | 70.96% | 21.33 | -0.65 | 0.515 | 0.19 |
| | No | 19 | 66.91% | 21.84 | | | |
| Male | Yes | 32 | 76.32% | 13.88 | -2.15 | 0.031 | 0.61 |
| | No | 38 | 64.28% | 23.41 | | | |

ES: effect size. Z: statistical value of the normal curve.
Source: Own elaboration.

## Questionnaire on resource perception

Table 5 shows the distribution of the responses given to each Likert scale value for the 10 statements. The proportion of participants selecting option 5 (Strongly agree) was >85% for all statements except item 3 (Using the resource improves my skills for calculating the concentration of solutions) and item 7 (I like the way the resource is designed). The highest rated statement was item 1 (The clinical context of the resource is appropriate to support meaningful learning of the topic).

**Table 5.** Responses (in percentages) to the perception questionnaire for the learning and technological development dimensions (n=34).

| Dimension | Statement | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Learning | 1. The clinical context of the resource is appropriate to support meaningful learning of the topic. | 0.00 | 0.00 | 0.00 | 2.94 | 97.06 |
| | 2. Using the resource improves my perception of the importance of the topic for my future practice. | 0.00 | 0.00 | 8.82 | 5.88 | 85.30 |
| | 3. Using the resource improves my skills for calculating the concentration of solutions. | 0.00 | 0.00 | 2.94 | 32.35 | 64.71 |
| | 4. The clinical and ethical context of the resource enhance my motivation towards gaining knowledge of the topic. | 0.00 | 0.00 | 2.94 | 5.88 | 91.18 |
| | 5. I would like to see the resource developed further to cover other aspects of solutions in the clinical context. | 0.00 | 0.00 | 2.94 | 2.94 | 94.12 |
| Technological development | 6. It is easy to navigate through the resource. | 0.00 | 0.00 | 0.00 | 11.76 | 88.23 |
| | 7. I like the way the resource is designed. | 0.00 | 0.00 | 0.00 | 26.47 | 73.53 |
| | 8. It is advisable to invest resources in the design and development of this type of teaching tools. | 0.00 | 2.94 | 5.88 | 0.00 | 91.18 |
| | 9. It would be worthwhile for teachers to spend some of their time designing these types of resources. | 0.00 | 0.00 | 2.94 | 2.94 | 94.12 |
| | 10. It would be worthwhile to promote student participation in the development of these types of educational resources. | 0.00 | 0.00 | 8.82 | 5.88 | 85.30 |

Source: Own elaboration.

The open question was answered by 11 of the 34 participants. The suggestions were classified into 4 inductive categories: 7 in New Topics, 2 in More Characters/Cases, 1 in More Disclosure, and 1 in Better Design.

## Congress Forum

The comments from the 116 participants in the *Solutions with Empathy* learning resource forum were classified into 5 inductive categories: clinical and ethical context, technological development, empathy, suggestions, and questions. In each category, subcategories were created to organize the information (Table 6).

**Table 6.** Categories and subcategories for comments in the congress forum.

| Category | Subcategory | Number of comments | Example |
|---|---|---|---|
| Clinical and ethical context | Meaningful learning | 17 | "It is a great initiative to promote meaningful learning by combining curricular content and stories of real-life people" |
| | Applicability in practice | 14 | "I think this is an important teaching resource for reinforcing interconnected knowledge. The applicability in the life of the students is very evident" |
| | Motivation to learn | 13 | "It is a great tool to support learning and motivate students" |
| | Critical thinking | 8 | "It is a strategy that allows the student to reflect critically, generating critical thinking" |
| | Autonomous learning | 5 | "Synergy between chemistry and health, an excellent way to encourage autonomous learning in students" |
| Technological development | Design and usability | 26 | "The resource is easy to use and is very useful for working on solutions with students" |
| | Educational tool | 17 | "Great teaching tool, a good learning tool" |
| | Remote education | 3 | "Good tool for the remote education scenario we are currently experiencing" |
| Empathy | Citizen values | 12 | "Empathy is one of the most lacking traits in Colombian society, and these strategies help to develop more responsible citizens capable of solving the ethical problems of this sick society" |
| | Medical practice | 6 | "I appreciate the fact that they thought about empathy, which I consider important in this work for life, in this profession" |
| | Educational strategy | 3 | "From a pedagogical point of view, I think that using empathy to generate spaces for reflection, action and learning is a very good strategy" |
| Suggestions | To replicate it | 8 | "It would be good to implement this kind of tools in other subjects or areas of knowledge as well" |
| | To evaluate the results | 1 | "This should be taken to other environments and tested to identify the usefulness of these ideas" |
| Questions about the resource | About the cases and characters | 5 | "Was the creation of the characters with their stories based on previous experiences of the team, typical cases with patients, or something else?" |
| | About the development | 3 | "I would like to know how it was developed" |

Source: Own elaboration.

Of these 116 participants, 57 made positive comments about the clinical and ethical context in relation to learning, 46 focused on positive aspects of its technological development as a learning tool, and 21 highlighted the importance of working on empathy in medicine. Furthermore, 8 people suggested replicating the experience around other topics or areas of knowledge, and one suggested evaluating the strategy in other contexts. Eight people asked questions that were answered in the forum.

## Discussion

The objective of this study arose from the concern of the professors of the BQHS course at the UNAL regarding the improvement of their teaching practice based on a reflection on what and how to teach and learn in chemistry, and the purpose of this learning in students of programs other than chemistry, particularly medical students.

Discussions on what and how to teach science are not new[27] and, although they remain controversial, there is a certain degree of consensus on the usefulness of constructing curricula based on real problems that make sense in the context of students' professional training, rather than on assignments that turn them into experts in following a recipe by heart.[28] Consequently, approaches such as CBL (applied in the present research in the resource *Solutions with empathy*) have been developed, shifting away from teaching strategies based on extreme operationalization to provide more attractive learning experiences for students.[14] While the results reported on the use of this approach are consistently positive in relation to interest and motivation,[10,15] the findings vary from one study to another and are inconclusive with regard to cognitive aspects.[29,30]

The students of the BQHS course who filled out the perception questionnaire and the participants of the congress forum indicated that the clinical and ethical contexts of the teaching resource improve motivation and the perception of the importance of the topic, thus favoring meaningful learning, which coincides with what has been reported in recent research.[11,15] However, because the main criticism to CBL is that it relies too much on affective aspects of learning[30,31] such as interest and motivation, this study also evaluated its efficacy on cognitive aspects of learning.

Thus, in the present study, a statistically significant difference in the mean score of the posttest knowledge test was observed between the experimental and control groups ($p$=0.003), with a high ES (0.80). This positive effect of the CBL was also observed in the results of the regular course test, where a statically significant difference was found between users and non-users of the resource ($p$=0.0041), although the ES was medium (0.42). However, the improvement in the results after the intervention was different across sexes, with females performing better on the posttest knowledge test (which did not influence grades) than on the regular course test, while the opposite was true for males.

These results are consistent with the findings of Tashiro & Talanquer,[32] who found in their research on the reform of a university basic chemistry course that men tend to do better on tests, while women's results tend to be better in other activities. This fact may be related to a fear of failure when studying science at a university, which, according to Howe *et al.*,[33] affects women more than men, although it should be noted that this factor was not explored in the present study.

In any case, the clear increase in conceptual learning after the implementation of CBL indicates that this approach can also favor cognitive aspects of learning. This is in agreement with similar studies, such as those conducted by Bortnik *et al.*[34] with 50 Russian university students (second year of bachelor's degree programs) and by Broman

& Parchmann[35] with 20 Swedish students about to enter university. In these studies, it was concluded that to achieve an improvement in both the affective and cognitive aspects of learning, teachers should spend time designing appropriate contexts that allow students to apply their knowledge of specific topics or concepts to the solution of real-life problems relevant to their training.

On the other hand, in the present study, the technological development of the resource was also well rated by students and forum participants as a useful tool for learning. This is in agreement with the reports of García-Valcárcel & Tejedor,[19] who found that university students recognize that ICTs have great potential to support their learning and academic performance.

Finally, it should be noted that the positive results obtained in the present research were fostered by the reflective work of the BCHS professors who participated in the design of the resource, shared their experiences, and established relationships between content knowledge, pedagogical knowledge, and technological knowledge.[36] All this was aimed at designing new and better learning experiences in an appropriate context for medical students based on ethical dilemmas. In these contexts, emphasis was also placed on empathy in the doctor-patient relationship, which is very necessary for the humanization of the medical profession.[21]

The heterogeneity of the knowledge of the professors participating in this research about content, pedagogical approaches and technological aspects became an opportunity for collaborative learning. Mutual respect, supportive leadership and the sharing of values and principles about teaching and education facilitated learning among the professors through the exchange of good practices, which, according to Bolívar,[37] is a privileged mechanism for continuous teacher training and pedagogical innovation. In this regard, Austin & Murray[38] stated that when the pedagogical transformations are generated by a community of teachers, changes are sustained over time, better results are obtained, and teachers improve their practices, thus contributing to the learning of the entire community.

Finally, as a point for improvement of the present study, it is suggested to enrich the teaching resource with hyperlinks that allow greater autonomy in learning. The duration of the educational intervention may be considered as a limitation, and it would be beneficial to design and implement longer teaching experiences in the future and to evaluate the evolution over time of the impact on cognitive and emotional aspects.

## Conclusion

The CBL approach of the *Solutions with Empathy* learning resource was effective in enhancing the learning of the concentration units of chemical solutions among medical students, increasing their motivation for studying the topic and having a positive impact on the academic performance of those who used it. This result was brought about by the relationships between content knowledge, pedagogical knowledge and technological knowledge that the professors who participated in the research established, who also improved their skills by sharing practices with their peers in a learning scenario based on mutual respect and supportive leadership.

## Conflicts of interest

None stated by the authors.

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## Annex 1. Pretest knowledge questionnaire.

Dear student: Thank you for volunteering to participate in the *Solutions with empathy* project run by the Incubator of Pedagogical Innovation Initiatives of the DNIA by filling out the following questionnaire. Your answers will be treated confidentially and will be used only for academic purposes during the research. Your personal data will be treated in accordance with Law 1581 of 2012 and the Personal Data Policy of the Universidad Nacional de Colombia.

1. How many moles of alcohol are contained in 2.5 beer cans of 330mL (4.5% w/v)?

A. 80.7

B. 0.81

C. 0.32

D. 4.0

2. How many grams of alcohol are contained in 825mL of beer at 4.5% w/v?

A. 37.1

B. 183

C. 8.25

D. 33.0

3. A concentration of 338ppm is equivalent in mg/dL to:

A. 33.8

B. 3.38

C. 338

D. 0.338

4. What is the maximum molar blood alcohol concentration to test negative (below zero)?

Please note: Grade zero: between 20 and 39mg of ethanol/100mL of blood. Molecular weight ethanol: 46 g/mol

A. $4.13x10^{-3}$

B. 4.13

C. $1.9x20^{-3}$

D. 2.42

5. A level 1 alcohol content in the blood will result in the loss of the driver's license for one to three years. What is the range corresponding to level 1 alcohol content expressed as a molar concentration?

First level: between 40 and 99mg of ethanol/100mL of blood. License suspension between one and three years. Ethanol molecular weight: 46g/mol.

E. Between $8.7x10^{-3}$ and $2.15x10^{-2}$

F. Between $8.7x10^{-3}$ and $2.15x10^{-3}$

G. Between 0.40 and 0.99

H. Between 8.7 and 21.5

6. If 50mL of gin (40% w/v) and 250mL of (sic) wine (12% w/v) are mixed, the number of moles of alcohol in the mixture are:

A. 10.8

B. 0.43

C. 0.65

D. 8.01

7. Which of the following solutions has the greatest amount of alcohol (moles):

A. 100mL of wine with a concentration of 7.1% w/v
B. 50mL of vodka with a concentration of 40% w/v
C. 60mL of whiskey with a concentration of 36% w/v
D. 200mL of beer with a concentration of 4.9% w/v

8. If someone wants to have less than 10g of alcohol in their 200mL drink, what percentage (w/v) should they have?

A. Less than 5% w/v
B. Less than 3% w/v
C. Less than 2% w/v
D. Less than 1.5% w/v

9. How many grams of alcohol are contained in a 330mL beer with a concentration of 5.9% w/v?

A. 19.5
B. 17.7
C. 5.9
D. 56

10. Red wines usually have between 6 and 8% (w/v) of alcohol. How many milliliters of wine should a person drink in order not to exceed 10g of alcohol?

A. 125
B. 167
C. 80
D. 103

## Annex 2. Posttest knowledge questionnaire.

Dear student: Thank you for volunteering to participate in the *Solutions with empathy* project run by the Incubator of Pedagogical Innovation Initiatives of the DNIA by filling out the following questionnaire. Your answers will be treated confidentially and will be used only for academic purposes during the research. Your personal data will be treated in accordance with Law 1581 of 2012 and the Personal Data Policy of the Universidad Nacional de Colombia.

1. How many moles of alcohol are contained in 1.5 bottles of red wine of 750mL (12.0% w/v)?

A. 135

B. 2.93

C. 1.96

D. 4.0

2. If 250g of ethanol are diluted in 4.87L of blood, what is the molar concentration of ethanol in the blood?

A. 5.43

B. 1.12

C. 5.13

D. 2.36

3. How many grams of alcohol are contained in 650mL of gin at 40% w/v?

A. 260

B. 16.2

C. 40

D. 26000

4. If a person has 0.11 g/dL of alcohol in their blood, what is their level of intoxication?

Please note: Level zero: between 20mg and 39mg of ethanol/100mL of blood. First level: between 40mg and 99mg of ethanol/100mL of blood. Second level: between 100mg and 149mg of ethanol/100mL of blood. Third level: more than 150mg of ethanol/100mL of blood.

A. Level zero

B. First level

C. Second level

D. Third level

5. A concentration of 445 mg/dL is equivalent in ppm to:

A. 4450

B. 445

C. 44.5

D. 44500

6. What is the range of molar blood alcohol concentration for first level of alcohol intoxication?

A. Between $8.7x10^{-3}$ and $2.2x10^{-2}$

B. Between 18.4 and 45.5

C. Between $8.7x10^{-2}$ and $2.2x10^{-3}$

D. Between 1.8 and 4.5

7. If the LD50 of ethanol is 15 g/kg, how many 750 mL bottles of gin (40% w/v) should be consumed to cause the death of an individual weighing 70 kg?

A. 3.5

B. 14

C. 1.5

D. 5.0

8. The third level of alcohol in blood results in the loss of the driver's license for five to ten years. What is the molar concentration of alcohol in blood above which a person is considered to be at the third level of alcohol intoxication?

Third level: 150mg of ethanol/100mL of blood and above. Molecular weight ethanol: 46 g/mol

A. $3.26x10^{-2}$

B. $3.26x10^{-3}$

C. 0.307

D. 69.0

9. If 250mL of whiskey (40% w/v) and 150mL of (sic) wine (12% w/v) are mixed, the number of moles of alcohol present in the mixture are:

A. 2.56

B. 2.17

C. 1.79

D. 0.39

10. Which of the following solutions has the greatest amount of alcohol (moles):

A. 300mL of wine with a concentration of 9.1% w/v

B. 85mL of vodka with a concentration of 40% w/v

C. 90mL of whiskey with a concentration of 36% w/v

D. 600mL of beer with a concentration of 4.9% w/v

11. If someone wants to have less than 20g of alcohol in their 250mL drink, what percentage (w/v) should they have?

A. Less than 8% w/v

B. Less than 6% w/v

C. Less than 4% w/v

D. Less than 1.5% w/v

12. How many grams of alcohol does a person ingest if they drink a 350mL beer at 4.5% w/v?

A. 12.4

B. 15.8

C. 19.9

D. 10.8

13. How many grams of alcohol are contained in a 50mL glass of wine if the concentration is 2.6M?

A. 5.98

B. 13.0

C. 11.9

D. 5.60

14. Gin usually has between 35 and 40% (w/v) alcohol. How many milliliters of gin should a person drink in order not to exceed 10g of alcohol?

A. 25

B. 250

C. 10

D. 40

15. If a person drinks 50mL of 40% w/v whiskey, what is the molar concentration of ethanol in the blood?

A. $7.05x10^{-2}$

B. 0.34

C. $8.92x10^{-2}$

D. $3.40x10^{-2}$

## Annex 3. Perception questionnaire.

Dear student: Thank you for participating in the pedagogical challenge on the ways of expressing the concentration of solutions using the educational resource Solutions with empathy within the framework of the Incubator of Pedagogical Innovation Initiatives project of the DNIA. Your opinion about the resource is very important, so please fill out the following questionnaire, which will take you no more than 15 minutes. If you agree, your responses will be anonymous, and your personal data will not be collected. The results will be used only for academic purposes during the research.

I- Please indicate your level of agreement or disagreement with the following statements according to the following scale:

1. Strongly disagree
2. Partially disagree
3. Neither agree nor disagree
4. Partially agree
5. Totally agree

| Statement | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1. The clinical context of the resource is appropriate to support meaningful learning of the topic. | | | | | |
| 2. Using the resource improves my perception of the importance of the topic for my practice. | | | | | |
| 3. Using the resource improves my skills for calculating the concentration of solutions. | | | | | |
| 4. The clinical and ethical context of the resource enhance my motivation towards learning the topic. | | | | | |
| 5. I would like to see the resource developed further to cover other aspects of solutions in the clinical context. | | | | | |
| 6. It is easy to navigate through the resource. | | | | | |
| 7. I like the design of the resource. | | | | | |
| 8. It is advisable to invest resources in the design and development of this type of teaching tools. | | | | | |
| 9. Professors should spend some of their time designing these types of resources. | | | | | |
| 10. It would be worthwhile to promote student participation in the development of these types of educational resources. | | | | | |

II- Are there any suggestions you would make to improve the resource?