Strategies For Meaningful Chemistry Learning In College Students

Jimmy Henry López López[1] , Manuela Cecilia Castro Pacheco[2] , José Alfonso Anaya Olivella[3] , Oscar David Sierra Guzmán[4], Abel José Carreño Montenegro[5] , Yeris Karina Florez Avendaño[6] , Yeiner Dario Castro López[7]

[1]*Universidad Popular del Cesar, Colombia* Email: *jimmylopez@unicesar.edu.co*
ORCID: *https://orcid.org/0000-0001-7891-2219*
[2]*Universidad Popular del Cesar, Colombia* Email: *manuelacastro@unicesar.edu.co*
ORCID: *https://orcid.org/0009-0004-7225-0620*
[3]*Universidad Popular del Cesar, Colombia* Email: *joseanaya@unicesar.edu.co*
ORCID: *https://orcid.org/0009-0009-2348-761X*
[4]*Universidad Popular del Cesar, Colombia* Email: *oscarsierra@unicesar.edu.co*
ORCID: *https://orcid.org/0009-0002-1209-3171*
[5]*Universidad Popular del Cesar, Colombia* Email: *abelcarreno@unicesar.edu.co*
ORCID: *https://orcid.org/0009-0001-3665-4116*
[6]*Universidad Popular del Cesar, Colombia* Email: *ykflorez@unicesar.edu.co*
ORCID: *https://orcid.org/0009-0007-3121-8984*
[7]*Universidad Popular del Cesar, Colombia* Email: *ydcastro@unicesar.edu.co*
ORCID: *https://orcid.org/0009-0008-4217-5315*

The objective of the study was to propose meaningful learning strategies to reduce preconceptions about chemical periodicity in students of the Bachelor's Degree in Natural Sciences and Environment of the Popular University of Cesar. It was based on contributions from Limón and Carretero (2001), Díaz Barriga (2012), Martínez and Pozo (1999) and García Madruga (2008). The approach was explanatory-projective, with a quasi-experimental field design. 102 students and 12 teachers participated. Two equivalent groups were formed from the first semester (control and experimental; 45 students each) and 12 students corresponded to the last semester. The collection of information included observation (unstructured interview), survey of teachers using a 10-item questionnaire (Díaz Barriga, 2012) and knowledge test for students (Anaya, 2011); Both instruments had validity and reliability reported by their authors. The findings indicate that the previous ideas originate, mainly, in interferences of scientific vocabulary and misused analogies. Likewise, it was evidenced that teachers partially apply the recommended instructional strategies to promote meaningful learning. After the intervention, the experimental group showed notable differences with respect to the control, with a substantial reduction of preconceptions to low levels. As a result, a proposal for meaningful learning strategies was designed aimed at minimizing preconceptions about chemical periodicity in the program, articulating theoretical guidelines and operational guidelines for teachers. It is concluded that intentional mediation with meaningful strategies is effective in correcting alternative conceptions and strengthening the understanding of the periodic table and its regularities in the initial training of science teachers.

Keywords: preconceptions, instructional strategies, meaningful learning, chemical periodicity.

1. Introduction

In the initial training of science teachers, chemical periodicity articulates the understanding of atomic properties, periodic trends (ionization energy, atomic radius, electronegativity) and types of bonding. However, abundant evidence shows that students arrive with persistent preconceptions that interfere with the construction of scientific meanings (Limón, 2001; Díaz-Barriga, 2012; Vosniadou, 1998). In chemical education, these difficulties are observed, among others, in the dichotomous attribution "ionic versus covalent", the confusion between ionization energy and stability, or the use of heuristic rules to order electronegativities without considering the competition between effective nuclear charge and shielding (Hunter, 2022; Widarti et al., 2024).

From the framework of conceptual change, learning implies restructuring mental models through productive cognitive conflicts and explicit scaffolding that makes the student's assumptions visible (Duit & Treagust, 2003; Limón, 2001). In parallel, the theory of meaningful learning argues that new information acquires meaning when it is substantively anchored in the previous cognitive structure through organizers, conceptual hierarchies, and intentional mediation (Ausubel, 2000; Díaz-Barriga, 2012).

The convergence of both approaches has promoted didactic sequences that integrate activation of prior knowledge, controlled analogies, textual organizers and concept maps, together with practices of causal explanation between symbolic macroscopic submicroscopic levels (Talanquer, 2006, 2011; Nesbit & Adesope, 2006).

Recent evidence (2020 - 2025) confirms that active strategies with sufficient guidance outperform the lecture class in cognitive achievement, transfer, and motivation, and contribute to reducing gaps in underrepresented populations when their implementation is intensive and deliberate (Theobald et al., 2020; Ammar et al., 2023; Paçacı et al., 2024). In chemistry, recent reviews and studies recommend integrating diagnosis with concept inventories, formative feedback, and generative explanation tasks to promote lasting change (Hunter, 2022; Hagos et al., 2024; Hu et al., 2022). At the same time, digital resources such as interactive periodic tables can enhance the visualization of trends when incorporated into guided sequences and with criterion evaluation (Nsabayezu et al., 2023).

There is, however, ample evidence that "minimally guided inquiry" can overload the working memory of novices in domains with high intrinsic novelty; therefore, instructional design with explicit scaffolding, e.g., interleaved questions, pre-organizers, and progressive modeling is more effective for constructing mechanistic explanations (Kirschner et al., 2006). This does not imply discarding inquiry or problem-based learning, but rather articulating them with clear epistemic goals, substantive scaffolding, and formative assessment (Hmelo-Silver et al., 2007).

In the specific field of periodicity and linkage, recent studies synthesize error patterns and propose interventions that articulate diagnosis-intervention-evaluation: causal reasoning guides, criterion analogies, argumentation tasks with evidence, concept maps, and multiple representations (Hunter, 2022; Widarti et al., 2024; van Dulmen et al., 2023). This work is placed in this agenda and provides quasi-experimental evidence with undergraduate students, comparing traditional strategies against an instructional package of significant learning and measuring their effect in four areas: (i) relationship of periodicity with particles of the atom,

(ii) conceptualization of ionization energy and atomic radius, (iii) interpretation of electronegativity in periods and groups, and (iv) types of bonding according to bonded elements or atoms. This contributes to the systematization of effective practices for the reduction of preconceptions in chemistry, with special attention to the Latin American context of teacher training (Ammar et al., 2023; Paçacı et al., 2024). Playful strategies (rule games, cooperative dynamics) function as prior organizers and promote generative explanations with social interaction, conditions associated with conceptual change. In a recent study, they implemented a "Recycling Domino" for integrated waste management, observing substantive improvements in conceptual appropriation after a participatory workshop and game session – findings consistent with Ausubel's significant learning and transferable to university chemistry teaching (Dajil Turizo et al., 2024).

3. Study methodology

The positivist paradigm was adopted, oriented to the search for objective evidence and empirical verification through measurement and statistical analysis (Méndez, 2006; Hernández, Fernández, & Baptista, 2006; Hurtado, 2007). The study was descriptive-explanatory: it described the origin of previous ideas and the use of teaching strategies, and explained the effect of meaningful learning strategies on preconceptions in chemical periodicity (Arias, 2006; Tamayo, 2009; Rodríguez, 2005; Munch & Ángeles, 2007; Arias, 2012).

A quasi-experimental field design (pretest-posttest) was used with two intact groups (control and experimental), without random assignment, in a natural context (Hurtado, 2007; Hernández, Fernández, & Baptista, 2006; Chávez, 2007; Arias, 2006). The population was 114 individuals (first and last semester students and Chemistry teachers); the sample matched the population and was selected through non-probabilistic convenience sampling (Chávez, 2007; Álvarez & Díaz, 2004; Méndez, 2006; Cuesta, 2004; García, 2008).

The instruments included: (i) objective multiple-choice test for students (19 items) that evaluated four areas of periodicity (Anaya, 2011) and was interpreted with a scale of our own elaboration (2016); (ii) self-administered questionnaire to 12 teachers on significant learning strategies (10 items, three alternatives) standardized by Díaz Barriga (2012); and (iii) semi-structured interviews with 20 students to identify previous ideas (Bisquerra, 2009).

Statistical processing included ANOVA to compare means between groups (Tapia, 2007), calculation of arithmetic means (Carrero, 2006) and significance contrast $p < 0.05$ (Hernández, Fernández & Baptista, 2006). The interviews and the questionnaire with teachers were summarized in frequency tables (absolute and relative) (Hernández, Fernández, & Baptista, 2006). The procedure followed four stages: problem statement; theoretical framework; methodological framework (KR validation and reliability); and analysis of results to propose strategies for meaningful learning.

4. Results

102 students and 12 teachers were analyzed. The pretest-posttest comparison between the control group (traditional strategies) and the experimental group (significant learning strategies) included ANOVA, Tukey, and Student's t; additionally, the distribution of scores (Chi-square) was evaluated.

1) Origin of previous ideas
Interference with scientific vocabulary predominated (25%), followed by analogical origin (20%). The sensory/experience and oral expression components contributed 15% each.

Table 1 Origin of previous ideas (n=20 interviews)

Indicator	Fa	Fr (%)
Interference with scientific vocabulary	5	25
Analog	4	20
Sensory/Experiences	3	15
Speaking	3	15
Social	2	10
Cultural	2	10
Anthropomorphization	1	5
Total	20	100

Note. Fa = absolute frequency; Fr = relative frequency.

2) Teaching strategies for meaningful learning
Teachers report high use of objectives and interleaved questions (91.7% "always"). In contrast, there is a low use of concept maps (50% "never"), analogies (41.7% "never") and textual organizers (41.7% "never").

Table 2 Use of strategies by teachers (n=12, summary)

Strategy	"Always" %	"Never" %
Objectives	91,7	0,0
Interleaved Questions	91,7	0,0
Signage	25.0 ("always"); 58.3 "almost always"	16,7
Previous organizers	41,7	25,0
Illustrations / Abstracts	25.0 ("always"); 41.7 "almost always"	33,3
Concept maps	25,0	50,0
Analogies	25,0	41,7
Textual organizers	25,0	41,7

Note. The items with the highest and lowest frequency of use are listed

3) Conceptual change by area (preconceptions)

In pretest, both groups showed a high presence of preconceptions in atom-periodicity, ionization/radium, and electronegativity; moderate in bond types (control ANOVA: p=0.039; experimental: p<0.001).

In post-test, the experimental group achieved low presence in all areas (Student's t: p<0.001 in 4/4). The control group improved in ionization/radium (p=0.019), electronegativity (p=0.001) and bonding (p<0.001), but maintained a high presence in atom-periodicity (p=0.168, ns).

Table 3. Pre-post comparison by group (means and presence level)

Area	Control Before (M)	Level	Control After (M)	Level	p	Exp. Before (M)	Level	Exp. After (M)	Level	p
Atom - periodicity	1,13	High	1,64	High	0.168 (ns)	1,18	High	4,51	Low	<0.001
Ionization and atomic radio	1,60	High	2,93	Moderate	0,019	1,76	High	5,24	Low	<0.001
Electronegativity (periods and groups)	1,62	High	3,11	Low	0,001	1,29	High	3,60	Low	<0.001
Link Types	2,46	Moderate	3,89	Low	<0.001	2,46	Moderate	3,91	Low	<0.001

Note. N=45 per group; levels according to the study scale; p = Student's t.

Comparison between groups in post-test. The experimental group outperformed the control in atom-periodicity and ionization/radium (p<0.001 in both). There were no differences in electronegativity (p=0.057) or bonding (p=0.777), as both groups were low in presence.

4) Overall performance in knowledge test

The averages went from 6.5→12.3 (control) and 6.6→17.2 (experimental). After the intervention, 84.4% of the experimental obtained >15 points versus 22.2% in the control (Chi-square p<0.001).

Table 4 Distribution of scores in the knowledge test

Timing	Group	<10 pts	10–15 pts	>15 pts	Medium ($\bar{x}$)	p
Before	Control	66,6%	17,8%	15,6%	6,5	**0,036**
	Experimental	64,5%	33,3%	2,2%	6,6	
After	Control	22,2%	55,6%	22,2%	12,3	<0.001
	Experimental	8,9%	6,7%	84,4%	17,2	

Note. Percentages are shown by before and after ranges; p = Chi-square per moment.

Key finding

Meaningful learning strategies were effective and superior to traditional ones in reducing preconceptions in all areas of the construct in the experimental group (low post-test presence) and in raising performance in the knowledge test (higher proportion >15 points).

The findings show that the instructional package based on meaningful learning generated a substantial reduction in preconceptions about chemical periodicity and an increase in performance in the experimental group, an effect that was not observed with the same magnitude in the control group that worked with traditional strategies. This confirms that alternative conceptions are not corrected by passive exposure to content, but by sequences that activate prior knowledge, provide explicit scaffolding, and use formative verification.

As for the origin of preconceptions, the interference of scientific vocabulary with everyday language and the use of non-criterion analogies predominated. This pattern is consistent with the literature on alternative conceptions: students tend to replace technical terms with commonly used meanings or to extrapolate analogies from the everyday context without semantic control (Crespo & Limón, 2000; Vosniadou, 1998; Driver, 2002).

The pretest-posttest contrast showed that, after the intervention, all the areas evaluated in the experimental group were shifted to low levels of presence of preconceptions (relationship with atom particles; ionization energy and atomic radius; electronegativity; types of bonding). This is in dialogue with recent evidence that supports active strategies with sufficient guidance, pre-organizers, interleaved questions, progressive modeling, conceptual maps/organizers, and generative explanation tasks, and advises against minimally guided inquiry for novices due to working memory overload (Theobald et al., 2020; Ammar et al., 2023; Paçacı et al., 2024; Kirschner et al., 2006; Hmelo-Silver et al., 2007).

In the specific field of periodicity and linkage, recent reviews document recurrent errors ("ionic vs. covalent" dichotomy, confusions about electronegativity and stability, heuristics to order trends) and recommend articulating diagnosis–intervention–assessment with multiple representations (macro-submicro-symbolic), criterion analogies, and formative assessment (Hunter, 2022; Widarti, Sari & Wahyudiati, 2024; Hagos, Assefa, & Kousathana, 2024; Hu, Ding, & Chen, 2022). Our results provide quasi-experimental evidence in the teacher training population in Latin America that confirms superior impacts of the significant package compared to the lecture class.

Regarding teaching practice, a selective use of strategies (objectives and interspersed questions) and underuse of complementary tools (concept maps, analogies, textual organizers) were observed, which limits the conceptual reconstruction of students. This finding is

consistent with the need to move from the occasional use of "techniques" to integrated didactic sequences with clear epistemic goals and formative assessment (Díaz-Barriga, 2012; Talanquer, 2006, 2011).

Validity and limits: Quasi-experimental field design with intact clusters and non-probabilistic sampling strengthens ecological validity, but restricts strict causal inferences and generalization. Even so, the convergence of ANOVA, Tukey's HSD, Student's t, and chi-square supports pattern consistency and gradient improvement in the experimental group. Future research should estimate effect sizes (e.g., Cohen's d/partial η^2), employ models of covariance (ANCOVA), and perform longitudinal follow-ups of conceptual retention.

Implications: it is recommended to institutionalize teacher development programs aimed at (i) planning sequences of conceptual change with activation of previous knowledge and explicit scaffolding; (ii) to use multiple representations and criterion analogies; (iii) integrate formative assessment with inventories of concepts; and (iv) explore guided digital scaffolding (e.g., interactive periodic tables) that favors trend visualization and deliberate practice (Nsabayezu et al., 2023).

Our findings on the reduction of preconceptions under meaningful learning strategies converge with local experiences where guided gamification favors the reorganization of meanings. In the "Domino of recycling", the transition from regulatory ignorance to explicit recall of categories after the workshop-game cycle indicates that active sequences with scaffolding exceed traditional exposure to induce conceptual change (Dajil Turizo et al., 2024).

5. Conclusions

Overall, the findings confirm the efficacy of meaningful learning strategies to reduce preconceptions about chemical periodicity in undergraduate students. Initially, a high presence of alternative ideas was verified in the relationship periodicity - particles of the atom, in ionization energy/atomic radius and in electronegativity, mainly attributable to the interference of the scientific vocabulary and, secondly, to misused analogies.

Although teachers reported frequent use of objectives and interleaved questions, limited application of concept maps, guided analogies, and textual organizers was observed. After the intervention, the control group showed partial improvements (ionization: high→moderate; electronegativity: high→low; chemical bonding: moderate→low) but maintained a high level of preconceptions in atom-periodicity; in contrast, the experimental group evidenced significant reductions in all areas until they were in low presence. This pattern was reflected in performance: averages in the knowledge test went from 6.5→12.3 (control) and 6.6→17.2 (experimental), supporting the greater impact of sequences with significant scaffolding compared to traditional approaches.

Pedagogically, it is recommended to explicitly address scientific vocabulary (contrast with everyday language), design previous organizers, integrate interleaved questions, concept maps and controlled analogies, and incorporate active and playful activities that promote semantic restructuring and verification of understandings. It is suggested to strengthen teacher training in the design of sequences for conceptual change and in aligned formative assessment.

Among the limitations, the quasi-experimental design with intact groups, the specific institutional context, and the mainly short-term measurement limit the generalization. Future research should include longitudinal follow-ups (retention and transfer), multiple cohorts,

triangulation with qualitative evidence (interviews/observations), and cross-family comparisons of strategies, e.g., organizer variations, simulations, cooperative learning). In summary, the study fulfills its general objective and provides a set of operational strategies to reduce preconceptions about chemical periodicity, with clear implications for the curriculum and teaching practice in the initial training of science teachers.

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