TPACK: Innovation in the teaching of chemistry during the covid-19 pandemic in high school students

TPACK: innovación en la enseñanza de química durante la pandemia covid-19 en alumnado de bachillerato

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Keywords
Educational innovation; ICT; organic chemistry; TPACK

ABSTRACT

Education with online tech tools during the pandemic caused by covid-19 was the principal alternative due the restrictions worldwide, and its insertion required models that made them more efficient. The aim of this research was to know the effectiveness of the TPACK model making use of ICT in the teaching-learning process of the subject Chemistry II in upper middle level, during the contingency. It was a quasi-experimental study with A-B-A design, involving 152 fourth semester high school students from a public institution, distributed into four experimental groups in which an educational program was implemented. Three tests were designed and validated by expert judgement, with α = .91, .92 and .93, and were applied as a pre- and posttest. The educational program was developed in the TPACK model, using ICT. The data were analyzed through the student's t-test and showed improved performance of the participating students after the intervention. An innovative design of instruction was generated with the TPACK model, which demonstrated its effectiveness for the insertion of technology for teaching that can be generalized to the instruction of other chemistry topics in high school.

Palabras clave
Innovación educacional; TIC; química orgánica; TPACK

RESUMEN

La instrucción con herramientas tecnológicas en línea durante la pandemia provocada por la covid-19 fue la principal alternativa debido a las restricciones en todo el mundo, y su inserción requirió de modelos que las hicieran más eficientes. El objetivo de esta investigación fue conocer la eficacia del modelo TPACK haciendo uso de las TIC en el proceso de enseñanza-aprendizaje de la asignatura Química II en nivel medio superior, durante la contingencia. Fue un estudio cuasi-experimental con diseño A-B-A, en el que participaron 152 estudiantes de cuarto semestre de bachillerato de una institución pública, distribuidos en cuatro grupos experimentales a los que se les aplicó un programa educativo. Se diseñaron tres pruebas que fueron validadas mediante juicio de expertos, con α = .91, .92 y .93, además de que se aplicaron como pre y posprueba. El programa educativo se desarrolló en el modelo TPACK, con apoyo de las TIC. Los datos se analizaron a través del contraste t de student y mostraron una mejora en el rendimiento del alumnado participante después de la intervención. Se generó un diseño innovador de instrucción con el modelo TPACK, que demostró su eficacia en la inserción de la tecnología para la enseñanza que puede generalizarse a la instrucción de otros temas de química en bachillerato.

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INTRODUCTION

In March 2020, 28 countries in Latin America and the Caribbean suspended face-to-face classes due to the pandemic caused by covid-19, affecting nearly 160 million students (ECLAC, 2020; ECLAC-Unesco, 2020), resulting in a forced migration to virtual education in a short time (Bao, 2020; García-Peñalvo, Corell, Abella-García and Grande, 2020; Ramírez-Montoya, 2020; Reyes and Quiróz, 2020; Vollbrecht, Porter-Stransky and Lackey-Cornelison, 2020).

Given this situation, immediate and effective solutions were required to offer education in any region of the world, so the implementation of virtual platforms for distance education turned out to be the main alternative (Ramírez-Montoya, 2020; Rodríguez *et al.*, 2020; Unesco-IESALC, 2021). As a result, online education increased 62% in Latin American countries, including Mexico, between the first and second quarter of 2020 (ECLAC-UNESCO, 2020).

Through virtual education, which makes use of different digital tools, learning environments adapted to the covid-19 context were created, which were more personalized, flexible and inclusive (Gelles *et al.*, 2020; Jimola and Ofodu, 2021; Stenhoff, Pennington and Tapp, 2020; Yates *et al.*, 2021). Likewise, through virtual platforms, classes were implemented synchronously and asynchronously (Becerra, Quintana and Reyes, 2020; Vollbrecht *et al.*, 2020).

Faced with this health crisis, teachers became learning facilitators and designers of virtual learning environments (Unesco, 2021). Some educational institutions in different countries already had educational programs hosted on specific platforms for distance education, which allowed them to adapt quickly to the global contingency (Ramírez-Montoya, 2020). In Mexico and Latin America, because virtual education is incipient, most institutions made great efforts to choose and build educational strategies focused on the use of information and communication technologies (ICT) (Bizberge and Segura, 2020; Ramírez-Montoya, 2020), considering that students lack electronic devices and have limited access to the Internet (INEGI, 2020; Unesco, 2021; Unesco-IESALC, 2021).

These were not the only challenges, since it was necessary to generate and test effective teaching strategies that would enhance the use of digital technologies for quality online instruction. In view of this, the Technological Pedagogical Content Knowledge (TPACK) model became relevant, conceived for an effective insertion of technology in teaching in virtual environments (Bento, Sommer, & Rocha, 2021; Koehler, Mishra, & Cain, 2015; Mishra, 2019). The TPACK model has been used for some time with good results in teacher training, seeking to confer to teachers the necessary skills to optimize the insertion of ICT in teaching (Baracaldo, 2019; Tanak, 2020).

It is a comprehensive techno-pedagogical model for virtual environments, it involves the interrelations between three main elements: the disciplinary area (contents of the subject to be taught), the pedagogical area (methods used for teaching-learning, academic goals to be met upon completion of instruction in the virtual context) and the technological area (technological resources and tools, ICT) (Koehler, 2012; Koehler and Mishra, 2009; Koehler *et al*, 2015; Roig, Mengual and Quinto, 2015; Rosenberg *et al.*, 2015; Santos and Castro, 2021; Zhang and Tang, 2021).

These basic elements interact with each other, in order to optimize teaching-learning in virtual environments, so three combinations are generated from these three elements. The first one is the pedagogical knowledge of content, that is, instructional methods that allow access to the subject in a more understandable way for the students; the second one is the technological knowledge of content (the way in which technology and content influence each other), so the teacher makes use of ICT to access the content of the subject taught; and the third combination is the so-called pedagogical technological knowledge, which shows how the teaching-learning process can vary and also must be adapted to the type of technology used (Koehler *et al.*, 2009; Shulman, 1986). The TPACK model allows identifying the technological resources that potentiate the learning of specific content, applying the most appropriate for each form of instruction, it also allows knowing the context in which the implementation will take place (Mishra, 2019; Rosenberg and Koehler, 2015).

In the pedagogical area, the TPACK model considers the use of cooperative learning, the flipped classroom and formative assessment, elements considered in didactic sequences for instruction. These are defined as an articulated and orderly set of activities that make up the learning units and are built according to the learning objectives, the internal order is crucial to achieve them (Zabala, 2000). In didactic sequences, activities must be designed in such a way that they generate meaningful situations for students (Díaz-Barriga, 2013); a sequence should begin with an initial production, follow a series of workshops and close with considerations to identify the students' progress (Soler, Villacañas de Castro & Pich, 2013).

For a sequence to be designed integrating cooperative learning, it must include: activation, attention guidance, personal interaction, information processing, recapitulation, evaluation and SSMT (sense, meaning, metacognition and transfer; Ferreiro and Espino, 2009). Cooperative learning is understood as an instructional method in which students work together in small groups to extend their own learning and that of others (Johnson and Johnson, 2014; Johnson, Johnson and Holubec, 1999;

Slavin, 2014). In order for it to achieve shared learning goals, the following five essential elements must be integrated into a cooperative classroom:

- Positive interdependence. Each team member thinks of himself as linked to the others, and will only achieve his goals if the others do so as well (Deutsch, 1962; Johnson & Johnson, 2005; Johnson, Johnson, & Smith, 2014; Slavin, 1996). If students value working together each member will be motivated for mutual teaching, which ensures that everyone understands the subject matter (Slavin, 1996 and 2014).

- Individual responsibility. Each team member will be responsible, contribute, but also receive input; they first learn together to then perform better as individuals (Johnson *et al*., 1999; Slavin, 1996).

- Social skills. Members develop interpersonal skills with the same intensity as academic skills so that cooperative work bears fruit in decision making, conflict management and leadership (Johnson *et al*., 1999).

- Promoting interaction. Interaction in a dynamic environment prevails in helping one another, praising each other's efforts to learn, and favoring dialogue, promoting feedback, leading to overall success (Johnson *et al*., 1999; Johnson *et al*., 2014).

- Group processing. It represents a moment of reflection of the cooperative team that derives in making decisions and commitments aimed at achieving better team performance (Johnson *et al*., 1999; Johnson *et al*., 2014).

Another essential element in the TPACK model is the flipped classroom, as it promotes flipped learning, which is a pedagogical approach in which direct instruction is shifted from individual learning to group learning, transforming the group space into an interactive learning environment in which the educator leads students to creatively engage in the subject matter to make an application of their learning (Bergmann and Sams, 2012; Flipped Learning Network [FLN], 2014), such that what was traditionally done in class is now done at home, while what was done as homework is now completed in class. Achieving flipped learning requires four fundamental pillars (FLN, 2014): flexible environment, which promotes multiple learning styles; learning culture, which fosters more inclusive student-centered learning (Hwang, Lai, & Wang, 2015); targeted content, through differentiated instruction to facilitate learning for all (Hwang *et al*., 2015); and professional facilitator, through reflective instruction, aimed at providing feedback on student performance through educational assessment.

When working in a flipped classroom, students are introduced to the subject to learn before class, reviewing videos, presentations, tutorials, series of exercises, doing research, among other activities that are usually chosen or designed by the teacher (González and Abad, 2020; Reyes, Villafuerte and Zambrano, 2020). Subsequently, in face-to-face or synchronous classes, already with some learning about the topic (Prieto, Barbarroja, Álvarez and Corell, 2021; Reyes *et al*., 2020), various learning activities (exercises, discussions, information organizers, forums, questionnaires, among others) are carried out, mostly in a cooperative manner (Gámiz, 2017; González *et al*., 2020; Reyes *et al*., 2020), to deepen, review, revise and provide feedback about the topic in question (Hernández, Prada, & Gamboa, 2020).

Both methodologies (cooperative learning and flipped learning) promote making necessary adjustments to the instructional process based on the context, students' needs and content characteristics, for greater effectiveness of their application (Bergmann *et al*., 2012; FNL, 2014; Johnson and Johnson, 2014), which aligns perfectly with the TPACK model. Cooperative learning strategies with the use of technology have shown that they can lead to a significant increase in learning in different knowledge areas, such as chemistry (Hassan and Salihu, 2020; White, Dubrovskiy, and Peters, 2020; Qiang, 2018). By integrating the TPACK model and cooperative learning, a better perception of teaching digital competence is visualized by inserting cooperative activities with digital support (Meroño, Calderón and Arias-Estero, 2021).

By implementing the TPACK model, a greater pedagogical knowledge is achieved, which facilitates the use of teaching methods, such as cooperative learning (Bingimlas, 2018) and the inverted classroom, achieving its insertion in a hybrid learning mode, which decreases the amount of time in face-to-face work, due to the fact that most of the learning of the contents is done outside the classroom and the face-to-face work is channeled in answering questions and providing feedback (Eichler and Peeples, 2016), which is adjusted to the current school demands in the context of the pandemic by covid-19.

In relation to these adjustments in the learning process, it is important to develop a type of assessment in line with innovation strategies of the TPACK model, so it is suggested to use formative assessment, since through this, teachers make instructional decisions based on the information gathered, giving feedback to students to improve their own performance (Brookhart, 2009) and motivate their learning (Brookhart, 2009; Leenknecht, Wijnia, Köhlen, Fryer, Rikers, & Loyens, 2021). Educational evaluation serves a regulatory reason, it is oriented to the student's approaching the training objectives by supporting the learning process, and it is comprised as part of a cooperative work, of a trust contract, where help is mutual (Perrenoud, 2001).

Based on the above, the benefits of using the TPACK model have demonstrated its applications in different areas of science, in various regions of the world and at different educational levels, mainly at the upper secondary and higher education levels. For example, in Lesotho, Africa, in the teaching of high school chemistry through the TPACK model showed its effectiveness in learning, as well as in improving the cognitive performance of students (Bohloko, Makatjane, George, & Mokuku, 2019). In secondary schools in Nigeria, teaching proficiency in the TPACK model was shown to significantly influence students' scientific literacy and attitude (Adebusuyi, Bamidele, & Adebusuyi, 2020).

In Asia its usefulness has also been proven, for example in Israel the TPACK framework facilitated the creation of materials for high school students in the subject of chemistry for online teaching during the pandemic (Rap *et al.*, 2020). In Indonesia, it was reported how the application of the teaching material called: TPACK-based history learning media led to increased learning in history at high school levels (Kurniawan and Sumargono, 2021). Meanwhile, in Brunei, in 2020, a study in secondary school showed that the implementation of lessons designed under TPACK led to an improvement in the understanding of osmosis and diffusion (Awang, Salleh and Shahrill, 2020).

In Latin America, specifically in Mexico, the design of a web application for the educational process on logarithm (AEL) under the TPACK model was described, which was shown to positively influence the understanding of theoretical aspects of logarithm in the area of financial mathematics (Salas, Gamboa, Salas, & Salas, 2020).

After a review of recent literature, it can be concluded that the TPACK model facilitates the effective insertion of technology in teaching; however, so far there are no studies with high school chemistry students in Mexico, focused on the learning of organic chemistry; likewise, it is worth mentioning that in other educational levels the use of the TPACK model is still scarce. Studies from other countries show the effectiveness of teaching with technology under the TPACK framework to improve grades and academic progress, so the objective of this research is to become aware of the effectiveness of the TPACK model, using ICT in the teaching-learning process of the subject Chemistry II in high school, during the pandemic caused by covid-19.

METHOD

Participants

A total of 152 fourth-semester high school students from the morning shift of a public high school located in the south of the State of Mexico participated: 103 females (67.8%) and 49 males (32.2%), with an age range between 16 and 17 years (with an average of 16.2 years).

Design

The design of this research is quasi-experimental with A-B-A arrangement (Kazdin, 2009). In Phase A, knowledge was assessed with a pre-test, while in Phase B an intervention program was implemented, finally the same tool is applied, as a post-test (Phase A). This design allows comparing the pre- and post-test phases to review the effectiveness of the intervention program (Benítez, Domeniconi, & Bondioli, 2019).

INSTRUMENTS

To meet the research objective, three instruments were used: Test I, Test II and Test III. These have content validity through the judges' criterion technique and obtained an Aiken's V index as follows: 0.98 for Test I, 0.99 for Test II and 1.0 for Test III.

Each of the tests measures the content established in the official curriculum and syllabus of the participating high school. Test I aims to measure knowledge about aliphatic hydrocarbons, their obtaining, properties and classification, and consists of 43 items, with a Cronbach's Alpha of $\alpha=0.91$. Test II seeks to measure knowledge about chemical formulas, carbon types, nomenclature and isomers, and consists of 41 reagents, with a Cronbach's Alpha of $\alpha=0.93$. Test III has the purpose of calculating knowledge about combustion reactions, minimum and molecular formula, as well as stoichiometric calculations, and is comprised of 27 reagents, with a Cronbach's Alpha of $\alpha=0.92$. Table 1 shows the description of each of the tests.

Table 1. Instruments (Test I, II and III), applied both as pre-test and post-test, before and after implementing the didactic sequences with the use of ICT under the TPACK model in the four experimental groups

Instrument	Subtopic	Quantity of reagents
1. Test I (questionnaire)	2.1 Obtaining 2.2 Classification 2.3 Physical and chemical properties	43
2. Test II (questionnaire)	2.4 Chemical formulas 2.5 Types of carbon in a chain 2.6 Nomenclature 2.7 Structural isomers	41

Instrument	Subtopic	Quantity of reagents
3. Test III (questionnaire)	2.8 Combustion reactions 3.1 Percentage composition 3.2 Minimal and molecular formula 3.3 Stoichiometric calculations in grams, moles, and combines 3.4 Limiting and excess reactant	27

Procedure

The project was presented to the school authorities in the 2021 school year and, once permission was obtained, the groups that would participate were identified; also, informed consent signed by the parents was requested. Since the research participants were inserted in four groups, these were taken as natural groups to receive the educational instruction program with the TPACK model. Each natural group served as the experimental group and the three phases of the experimental design, A-B-A, were applied. Table 2 shows the number of students in each experimental group.

Table 2. Distribution of students in the four experimental groups

Experimental group	Students		Experimental group	Students	
1	Women	27	3	Women	25
	Men	11		Men	12
	Total	38		Total	37
2	Women	31	4	Women	20
	Men	10		Men	16
	Total	41		Total	36
Total students	152				

Phase A. Pre-test

Before applying the educational program with the TPACK model for instruction with the use of ICT, the participating students' knowledge of each set of subtopics (as described in Table 1) was evaluated by applying the three objective tests as a pre-test, through Google Forms.

Phase B. Intervention with TPACK

During this phase, the four experimental groups received academic instruction in the TPACK model. One teacher, attached to the participating high school, was previously trained in the TPACK model and was responsible for operating the intervention program.

The topics taught through the TPACK model were: hydrocarbons and stoichiometry, both topics of Module II, called Aliphatic Hydrocarbons, of the Chemistry II course of the high-school fourth semester (official plan and syllabus), the subtopics can be seen in Table 1.

Twelve didactic sequences were designed for the educational intervention program, one for each subtopic. In these, activities designed for the insertion of technological tools were developed according to the TPACK model. The elements of the model and how they were applied in the design of the intervention program are described below: Content Knowledge (CK, Content Knowledge), refers to each of the subjects to be taught; Technological Knowledge (TK, Technological Knowledge), involves the hardware and software used in the intervention (see Table 3); Pedagogical Knowledge (PK, Pedagogical Knowledge), involves the methodology applied for instruction, brings together active methodologies such as cooperative learning and flipped learning, which have been shown to be useful in teaching-learning with the use of technological tools (Drozdikova-Zaripova and Sabirova, 2020; Ivone, Jacobs and Renandya, 2020; Sointu *et al.* , 2019).

Table 3. Platforms and software used during the intervention, according to their characteristics and use Microsoft's Teams platform was used as a learning management system

<table>
<tr><th rowspan="2">Development of resources and teaching material</th><th colspan="2">Synchronous and asynchronous classes</th></tr>
<tr><th>Tool</th><th>Use</th></tr>
<tr><td rowspan="5">YouTube
Chemsketch
MarvinSketch
KingDraw Chemical
genial.ly
PowToon
PowerPoint
Excel</td><td>Chemsketch
Marvinsketch
KingDraw Chemical</td><td>Representation and nomenclature of hydrocarbons</td></tr>
<tr><td>genial.ly
PowToon
PowerPoint</td><td>Presentations</td></tr>
<tr><td>Piktochart
Canva</td><td>Infographics</td></tr>
<tr><td>miMind
Cmaps Tools
Popplet</td><td>Conceptual maps</td></tr>
<tr><td>Excel</td><td>Stoichiometric calculations</td></tr>
</table>

Development of resources and teaching material	Synchronous and asynchronous classes	
	Tool	**Use**
Assessment (formative and summative)	Microsoft Forms, Google Forms	
Communication (synchronous and asynchronous) and cooperative work	Teams, WhatsApp, Messenger and Google Drive	

Note: The devices most used by students for synchronous and asynchronous classes were laptops, cell phones, desktop computers, and tablets. The teacher used a laptop and a cell phone.

In Pedagogical Content Knowledge (PCK), the methods of instruction, cooperative learning and inverted learning, adapted to the subjects, were used. In this area, as part of the formative evaluation process, which during the pandemic caused by covid-19 was one of the ways of evaluating online work (Filippi, Lafuente, Ballesteros and Bertone, 2021; Galarza-Salazar, 2021 and García, 2021), feedback strategies were used for tests that were applied in each subtopic, two of them were answered cooperatively (teams of three members), while another was answered individually.

The feedback was generated synchronously through Google Forms, considering the items with the most errors and students' doubts. The implementation of each didactic sequence designed, which included the moments of cooperative learning indicated by Ferreiro *et al*. (2009), sought that each cooperative team develop its abilities to work cooperatively in all sessions, especially during the synchronous classes. In each session, the teacher encouraged this work by guiding the students and giving them feedback, not only in terms of the objective tests, but also at each stage and always emphasizing the importance of everyone contributing equally in each activity. A fundamental moment was reflection, for which they made a cooperative report, while individually they answered a PNI (Positive-Negative-Interesting) chart (for more details of a sequence see Annex 1).

At the beginning of each topic, to work under the inverted learning methodology, as designed by Bergmann *et al*. (2012), before *examining* them in class, students individually reviewed various materials contained in the Teams platform (YouTube videos, genially presentations, Powtoon, among others, as described in Annex 1) and performed the required activities, mainly research, information organizers and exercises, working asynchronously to advance learning, always using the appropriate platforms and software for each particular topic (see Table 3 and Annex 1). During the class, when students had important notions about the topic, the activities could be combined with those of cooperative learning, as indicated by Gámiz (2017), González *et al*. (2020) and Reyes *et al*. (2020). The teacher's support in each synchronous session, answering questions, deepening and reviewing the topic, considering the individual needs and those of each cooperative team, was aimed at guiding students to achieve a better collective and individual performance. Feedback was essential throughout the intervention.

In the area of Technological Pedagogical Knowledge (TPK), which involves the use of the most appropriate technology for each form of instruction, Teams was used as a learning management system for synchronous classes and asynchronous activities (this is the platform activated through the high school), a WhatsApp group was created and, as indicated above, active methodologies (cooperative learning, flipped learning) and teacher management were used (for more details see Table 3 and Annex 1).

Regarding Technological Content Knowledge (TCK), which refers to the influence of technology and content, the most appropriate technological tools were used for each sub-theme (see Table 3). While in Context Knowledge (XK), which refers to the context of application, due to the pandemic, only online teaching with synchronous and asynchronous strategies was considered. In an integral way, the TPACK model (technological and pedagogical content knowledge), took for this distance participation of high school students Microsoft Teams as a learning management system to create a virtual learning environment with digital tools such as Piktochart, miMind and WhatsApp for cooperative work, and genially, PowToon, YouTube, ChemSketch, MarvinSketch and Forms for teaching-learning through cooperative learning and flipped learning for the instruction of hydrocarbon topics of the learning unit of the subject Chemistry II.

Table 3 shows the different platforms, applications, software and electronic devices that were most commonly used for teaching-learning during the intervention.

Phase A. Post-test

After the instruction, making use of ICT under the TPACK model, knowledge of the students of the four experimental groups was evaluated again, applying the three objective tests (see Table 1) as a post-test, to contrast the results before and after the educational intervention. Again, the application was done online, by Google Forms.

Data processing

To respond to the general objective of the research, a contrast of means of the three tests applied to the participating students during the pre- and post-treatment was developed, using SPSS software (v. 26). The Student's t contrast statistic was used, by means of contrasting related samples (since for each student the data of the pre- and post-treatment measures were compared). To determine efficacy, we identified whether there were significant differences in student learning in the four experimental groups before and after treatment.

RESULTS

Contrast of means for Test I

Table 4 presents the comparisons that were made for each item, before and after the instructional program.

Table 4. Contrast of means before and after the educational intervention of Test I

Factor of instrument	*Reagent*	*Pre Tx*	*Post Tx*	*gl*	*t*	*p*
1	1	1.2	1.8	151	-10.713	.000
2	2	1.6	1.9	151	-6.165	.000
3	3 a	1.3	1.6	151	-4.075	.000
4	3b	1.2	1.3	151	-1.547	.124
5	3c	1.3	1.5	151	-2.859	.005
6	3d	1.3	1.6	151	-3.372	.001
7	4 a	1.2	1.5	151	-4.290	.000
8	4b	1.4	1.6	151	-3.541	.001
9	4c	1.1	1.2	151	-2.581	.000
10	4d	1.2	1.3	151	-1.517	.130
11	5	1.7	1.9	151	-4.613	.000
12	6	1.5	1.8	151	-5.464	.000
13	7	1.3	1.7	151	-7.237	.000
14	8	1.1	1.5	151	-8.087	.000
15	9	1.2	1.8	151	-12.046	.000
16	10	1.2	1.6	151	-7.237	.000
17	11 a	1.1	1.7	151	-12.138	.000
18	11b	1.2	1.8	151	-11.770	.000
19	11c	1.1	1.7	151	-10.367	.000
20	11d	1.1	1.7	151	-11.224	.000
21	11e	1.4	1.8	151	-9.299	.000
22	12 a	1.1	1.7	151	-7.854	.000
23	12b	1.2	1.7	151	-8.369	.000
24	12c	1.3	1.7	151	-7.235	.000
25	13	1.4	1.8	151	-7.501	.000
26	14	1.2	1.4	151	-3.475	.000

Factor of instrument	*Reagent*	*Pre Tx*	*Post Tx*	*gl*	*t*	*p*
27	15 a	1.4	1.8	151	-7.815	.000
28	15b	1.1	1.6	151	-9.054	.000
29	15c	1.3	1.7	151	-7.126	.000
30	15d	1.3	1.7	151	-5.834	.000
31	15e	1.3	1.7	151	-6.080	.000
32	15f	1.3	1.7	151	-6.080	.000
33	15g	1.3	1.8	151	-6.819	.000
34	15h	1.2	1.6	151	-7.123	.000
35	15i	1.3	1.7	151	-5.452	.000
36	16	1.3	1.6	151	-6.035	.000
37	17 a	1.2	1.5	151	-5.478	.000
38	17b	1.1	1.4	151	-6.248	.000
39	17c	1.2	1.5	151	-4.544	.000
40	18	1.3	1.6	151	-4.368	.000
41	19	1.3	1.6	151	-5.976	.000
42	20	1.1	1.7	151	-10.039	.000
43	21	1.3	1.7	151	-7.831	.000

Tx = treatment; gl = degrees of freedom.

It can be seen that 90% of the responses showed statistically significant differences ($p \leq 0.001$) when performing the contrast before and after the educational intervention. Likewise, it has been seen that there were no changes before and after treatment in items 3b and 4d ($p > 0.01$). For item 4c no post-treatment learning was demonstrated, since both in the pre- and post-test the values are around 1, representing an incorrect response.

In Figure 1, the change in student learning in the Chemistry II learning unit can be visually identified when contrasting the pre-treatment phase (Phase A) with the educational intervention (Phase B), since there is no overlap due to the fact that in Phase A most of the answers are incorrect (values around 1), while in Phase B (treatment) their answers have values around 2, that is, they are correct; likewise, changes in the trend of Phase B are identified, since there is an increase with respect to the pre-treatment phase. The increase in student learning shown in phase B is maintained in the post-treatment phase (Phase A).

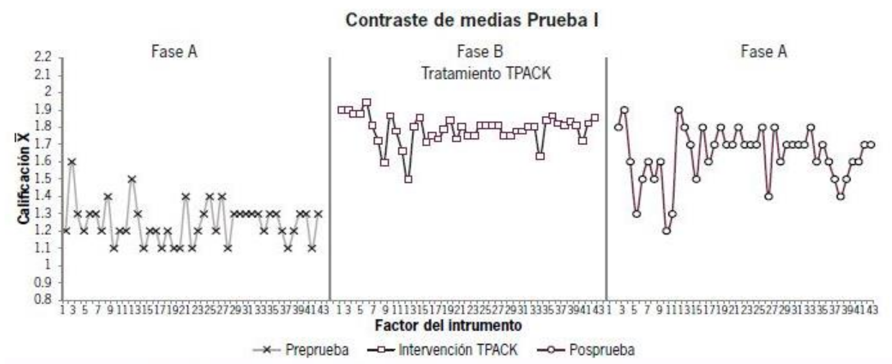

Figure 1. Answers in Test 1, before and after the intervention.

Contrast of means for Test II

Table 5 shows the comparison of means for each item before (pre-treatment of the educational innovation program using ICT) and after the educational intervention (post-treatment).

Table 5 shows that, out of 41 items compared, only three of them (items 22, 26 and 27a) were not significant ($p>0.05$), that is, 93% of the items showed statistically relevant differences ($p<0.05$) after the educational intervention. A block of items (12b to 12f) did show statistically significant differences ($p<0.05$), and it is also noted that the students answered correctly before and after the educational intervention.

Figure 2 visually identifies that there is a change in the students' learning, since in the pre-treatment phase the answers are incorrect (value 1) and in the educational instruction or treatment phase (B) the answers are correct (value 2), therefore there is no overlapping in the students' answers in these phases. A change in the trend of the responses is also identified, showing an increase in the treatment phase (B) that is maintained in the post-treatment phase.

Table 5. Contrast of means before and after the educational intervention of Test II

Factor of instrument	*Reagent*	*Pre Tx*	*Post Tx*	*gl*	*t*	*p*
1	1	1.3	1.6	113	-3.319	.001
2	2	1.1	1.6	113	-6.977	.000
3	3	1.3	1.5	113	-2.258	.020
4	4	1.2	1.7	113	-6.794	.000

Factor of instrument	*Reagent*	*Pre Tx*	*Post Tx*	*gl*	*t*	*p*
5	5	1.3	1.7	113	-4.587	.000
6	6 a	1.4	1.8	113	-2.864	.005
7	6b	1.3	1.9	113	-7.920	.000
8	6c	1.3	1.8	113	-4.975	.000
9	6d	1.5	1.9	113	-6.227	.000
10	7	1.1	1.8	113	-12.478	.000
11	8	1.4	1.8	113	-6.136	.000
12	9	1.1	1.8	113	-11.108	.000
13	10	1.2	1.8	113	-11.176	.000
14	11 a	1.3	1.9	113	-9.697	.000
15	11b	1.3	1.8	113	-8.829	.000
16	11c	1.2	1.8	113	-11.056	.000
17	11d	1.2	1.8	113	-12.291	.000
18	12 a	1.3	1.8	113	-4.441	.000
19	12b	1.7	1.9	113	-3.608	.000
20	12c	1.5	1.8	113	-2.883	.005
21	12d	1.6	1.8	113	-3.139	.002
22	12e	1.6	1.8	113	-3.139	.002
23	12f	1.7	1.8	113	-2.002	.040
24	13	1.0	1.8	113	-18.199	.000
25	14	1.0	1.8	113	-18.199	.000
26	15	1.0	1.8	113	-18.630	.000
27	16	1.0	1.8	113	-18.199	.000
28	17	1.0	1.8	113	-18.630	.000
29	18	1.0	1.8	113	-5.754	.000
30	19	1.3	1.9	113	-5.746	.000
31	20	1.2	1.7	113	-6.781	.000
32	21	1.2	1.6	113	-3.825	.000
33	22	1.3	1.4	113	-.533	.590
34	23	1.3	1.7	113	-5.408	.000
35	24	1.1	1.5	113	-3.734	.000
36	25	1.1	1.5	113	1.135	.000

Factor of instrument	*Reagent*	*Pre Tx*	*Post Tx*	*gl*	*t*	*p*
37	26	1.1	1.1	113	-1.839	.250
38	27 a	1.3	1.4	113	-2.355	.070
39	27b	1.2	1.4	113	-4.099	.020
40	27c	1.1	1.5	113	-2.987	.000
41	27d	1.3	1.7	113	-4.916	.003

Tx = treatment; gl = degrees of freedom.

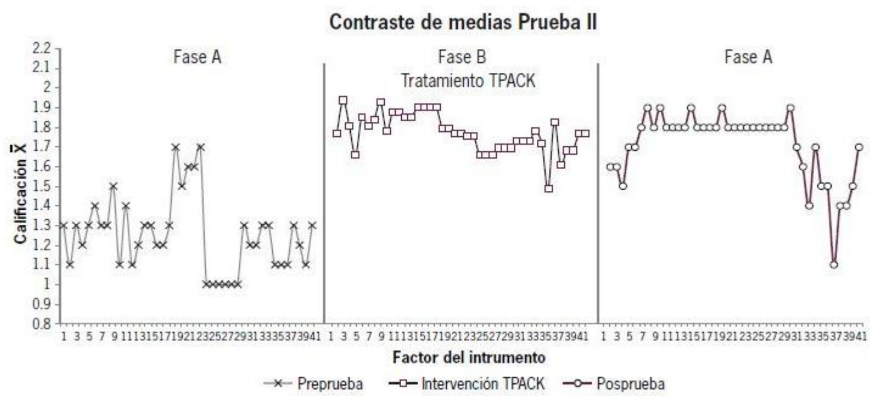

Figure 2. Answers in Test 2, before and after the intervention.

Contrast of means for Test III

Table 6 shows the contrast of means before and after the intervention. It can be seen that of the 27 items compared in Test III, all showed statistically significant differences (p<0.001) after the educational intervention.

Table 6. Contrast of means before and after the educational intervention of Test III

Factor of instrument	*Reagent*	*Pre Tx*	*Post Tx*	*gl*	*t*	*p*
1	1	1.4	1.9	109	-7.646	<0.001
2	2	1.1	1.6	109	-8.398	<0.001
3	3	1.3	1.7	109	-5.536	<0.001
4	4	1.2	1.7	109	-5.446	<0.001
5	5	1.4	1.9	109	-7.468	<0.001

6	6	1.3	1.9	109	-10.239	<0.001
7	7	1.2	1.9	109	-11.973	<0.001
8	8	1.2	1.9	109	-11.615	<0.001
9	9	1.2	1.9	109	-11.334	<0.001
10	10	1.3	1.8	109	-7.502	<0.001
11	11	1.1	1.8	109	-9.978	<0.001
12	12	1.2	1.8	109	-11.202	<0.001
13	13	1.3	1.9	109	-8.245	<0.001
14	14	1.2	1.8	109	-8.721	<0.001
15	15	1.1	1.8	109	-12.899	<0.001
16	16	1.2	1.9	109	-11.406	<0.001
17	17	1.2	1.7	109	-7.646	<0.001
18	18	1.2	1.7	109	-7.658	<0.001
19	19	1.2	1.6	109	-6.298	<0.001
20	20	1.2	1.7	109	-7.800	<0.001
21	21	1.2	1.7	109	-8.538	<0.001
22	22	1.2	1.7	109	-8.151	<0.001
23	23	1.1	1.7	109	-9.959	<0.001
24	24	1.2	1.6	109	-5.398	<0.001
25	25	1.3	1.7	109	-5.776	<0.001
26	26	1.2	1.8	109	-9.439	<0.001
27	27	1.2	1.8	109	-8.151	<0.001

Tx = treatment; gl = degrees of freedom.

Likewise, Figure 3 shows the students' answers graphically before the intervention (Phase A) which, as can be noted, were mostly incorrect (values around 1); after the TPACK intervention (Phase B) most of the answers are correct (with values around 2), so it can be seen that there is no overlap in the answers showing differences between phases A and B. Also, a change in the tendency of the answers is identified, so that the value of the students' answers increases in phase B (treatment), that is, in the pre-treatment phase the answers range in value 1 (incorrect) and in the treatment phase they change to value 2, which means correct.

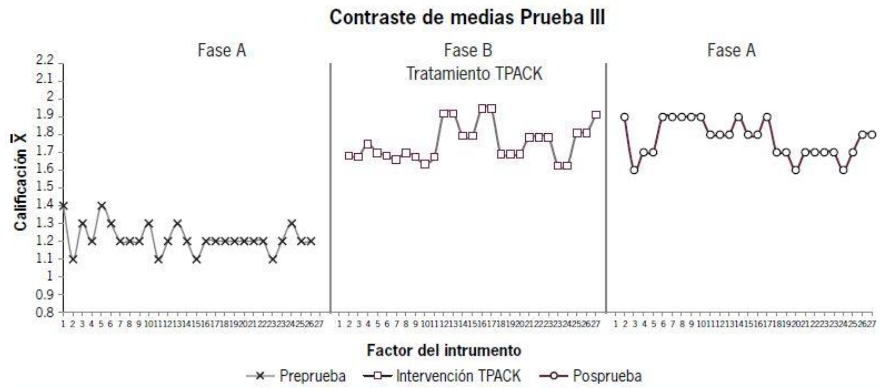

Figure 3. Answers in Test 1, before and after the intervention.

DISCUSSION

The purpose of the research was met, to become aware of how effective the TPACK model was in the teaching-learning process of the Chemistry II subject in high school during the pandemic caused by covid-19, since it was shown that this model leads to significant improvement in the learning of high school students in the subjects of hydrocarbons under the virtual mode, combining the use of ICT with pedagogy, and based on the content of the subject taught. Similar results were reported by Bohloko *et al.* (2019), who proved the effectiveness of the TPACK model for learning chemistry subjects, as well as the one reported by Fitriani, Susilawati and Linda (2020) and Perez *et al.* (2019), who proved the effectiveness of the use of ICT for hydrocarbon learning.

The element of the TPACK model called Technological Knowledge, which in this study was through the Microsoft Teams platform, was essential to facilitate the insertion and effective use of technological tools among the student body. Similar findings were found in other research (Giordano and Christopher, 2020; Olugbade and Olurinola, 2021), where Microsoft Teams was one of the most widely used platforms during the pandemic (Nguyen and Duong, 2021; Pal and Vanijja, 2020).

The insertion of active methodology (cooperative learning) as part of the pedagogical knowledge of the TPACK model in the intervention program, embodied in the didactic sequences designed for each hydrocarbon topic, improved students' performance after instruction, which corroborates what was achieved for learning other chemistry topics by applying cooperative learning (Hassan *et al.*, 2020; Qiang, 2018; White *et al.*, 2020); it also facilitated the application of this methodology by the teacher who provided the instruction, as reported by Bingimlas (2018).

Inverted learning was also an essential component of pedagogical knowledge in the instructional process, since in addition to contributing to online teaching during the pandemic, similar to what was reported by Elkhatat and Al-Muhtaseb (2021) for the instruction of other chemistry subjects, the integration with cooperative learning potentiated learning, since a better design of didactic sequences that were adapted to the context was achieved, a necessary requirement in any sequence according to Zabala (2000), considering the needs of the students, as referred by Bergmann *et al*. (2012). Similarly, the design achieved facilitated feedback, something characteristic of both methodologies (FNL, 2014; Johnson *et al*., 2014).

Technological pedagogical knowledge, implemented through cooperative learning and flipped learning with the use of technology, also contributed to this improvement in student learning, which supports the findings of Meroño, Calderón and Arias-Estero (2021) and Arora and Arora (2021), who determined an improvement in the academic performance of students applying cooperative learning and flipped learning with the use of technology under the TPACK model, respectively.

Two elements of the TPACK model fundamental to this research were Technological Knowledge of Content and Pedagogical Knowledge of Content. By using the most appropriate software for the characteristics of specific topics, their representation was simplified and their instruction was facilitated (Shulman, 1986). In this regard, the ChemSketch program was used to represent the structural formulas of hydrocarbons in the topics of chemical formulas, nomenclature, and structural isomers, because it simplifies the representation of any organic compound, which was also demonstrated in other studies (Pongkendek, Marpaung, & Parlindungan, 2021). In addition, the MarvinSketch program was employed for hydrocarbon naming, which allows the assignment of the name of any organic compound (Flynn *et al*., 2014). Thus, the TPACK program detailed here is in line with that described by Koehler *et al*. (2015), who consider that there is no specific way to insert technology for teaching, but this should be done under creative and innovative designs.

The adoption of online educational assessment as a feedback strategy (during the TPACK intervention phase) contributed to an improvement in student performance, an approach similar to that proposed by Filippi *et al*. (2021), Galarza-Salazar (2021) and Garcia (2021), who gave an educational guidance to assessment during the pandemic, in contrast to Basogain-Urrutia (2021), who describes cumulative assessment alternatives and how to avoid student cheating.

Adebusuyi *et al*. (2020) noted that the choice of the most appropriate digital tools for TPACK didactic sequences and the design of didactic material for instruction are essential for effective learning outcomes, and it has also been determined that the appropriate choice of tools simplified the teacher's task especially during the pandemic (Rap *et al*., 2020).

Although the design and implementation of the strategies proposed here were conceived to mitigate the pandemic problem that forced the suspension of face-to-face classes and to continue providing virtual education immediately (Bozkurt and Sharma, 2020; Oliveira, Teixeira, Torres and Morais, 2021; Rodriguez *et al*., 2020), the program is considered to be a construction that generated virtual and innovative learning strategies for the benefit of students (Digión and Álvarez, 2021; Unesco, 2021; Reyes *et al*., 2020; Fonseca and Mancheno, 2021).

One of the limitations in the research is that there was no control group, since due to the pandemic caused by covid-19 it was not possible to provide instruction without the use of ICT; therefore, for future studies it is recommended to use a control group to contrast the results obtained. Another limitation is not considering the evaluation of students' access to technological tools and not evaluating their competencies, since it has been identified that high school students are not digital citizens (Mendoza *et al*., 2019).

Conversely, one of the main strengths of this study is that technological tools were inserted in the instruction of hydrocarbon topics, emphasizing the pedagogical part (pedagogical knowledge), using cooperative learning and inverted learning, a situation that is not identified in similar research (Adebusuyi *et al*., 2020; Arora *et al*., 2021; Awang *et al*., 2020; Kurniawan *et al*., 2021; Salas *et al*., 2020).

CONCLUSIONS

Intervention through the program under the TPACK model led to an improvement in the learning of hydrocarbon topics in high school students in the subject of Chemistry II during the pandemic caused by covid-19, thus meeting the research objective.

Each element of the TPACK model contributed to an effective insertion of the appropriate technological tools for the instruction of each hydrocarbon topic through active methodologies, cooperative learning and inverted learning, favoring feedback to promote an improvement in the learning of the participating students.

Finally, the teaching model with the use of ICT under the TPACK model outlined in this research is an innovative alternative of virtual teaching that can be applied in a context different from the current one and serve as a guide for the design of other models for online instruction of topics other than organic chemistry in high school.

ANEXO 1

SECUENCIA DIDÁCTICA DISEÑADA BAJO EL MODELO TPACK

A continuación, se muestra una secuencia didáctica simplificada diseñada bajo los elementos del modelo TPACK.

Tema: Nomenclatura de alcanos.

Aprendizajes esperados indicados en el programa de asignatura Química II, del módulo II del que forma parte el tema de la secuencia

-Clasifica los hidrocarburos a través de su fórmula, propiedades físicas y químicas y nomenclatura (conceptual).
-Construye las fórmulas semidesarrolladas de distintos hidrocarburos a partir de su nombre y viceversa (procedimental).
-Muestra interés y compromiso en el trabajo en equipo. Valora el papel de la tecnología como una herramienta de apoyo en su aprendizaje (actitudinal).

SECUENCIA DIDÁCTICA TPACK PARA EL TEMA DE NOMENCLATURA DE ALCANOS
ELEMENTOS CK, PK Y TK DEL MODELO TPACK EN LA SECUENCIA

CK	Nombres sistemáticos IUPAC de alcanos de cadena abierta lineales y ramificados Nombre sistemático IUPAC de alcanos de cadena cerrada (cíclicos) sin ramificaciones y sin ramificaciones Conceptos de fórmula general de alcanos Nombres sistemáticos IUPAC de grupos alquilo o ramificaciones		
PK	Docente: Indicar, dar seguimiento y verificar que se cumplan los objetivos de aprendizaje Solicitar, revisar, evaluar y retroalimentar cada actividad Orientar, supervisar, apoyar y hacer sugerencias a los estudiantes en cada etapa de las actividades Integrar y supervisar los equipos cooperativos Verificar y dar seguimiento a las actividades propias del aprendizaje cooperativo y aprendizaje invertido Estudiante: Revisar previamente el material didáctico diseñado por el docente (videos y actividad previa) Investigar, organizar la información y elaborar un mapa conceptual de nomenclatura de alcanos Realizar las series de ejercicios: Nombre IUPAC de alcanos simples a través de rompecabezas Resolver, revisar y corregir cooperativamente las pruebas objetivas Participar en la actividad, brindar preguntas y recibir respuestas para contrastar la información Elaborar informe escrito cooperativo y cuadro PNI Participar en las actividades propias del aprendizaje cooperativo y aprendizaje invertido		
TK	*Hardware*	Computadora, tableta y teléfono inteligente	
	Software	LMS (sistema para gestión de aprendizaje)	Teams
		Gestión de proyectos (equipo cooperativo)	Trello
		Comunicación	Messenger, WhatsApp y Microsoft Teams
		Bases de datos	Google Scholar, Redalyc, SciELO
		Plataformas y *apps*	Para Química: KingDraw Chemical, Marvinsketch y Chemsketch
			Generales: Powtoon, genially, YouTube, Google Docs, Cmap Tools y miMind

Aprendizaje cooperativo					Elemento del modelo TPACK (TCK, TPK, PCK) que más se asocia a la actividad*
			AI		
Fases	Momento	Actividades del docente		Actividades de los estudiantes	
Inducción	Activación	Solicita: 1. Realización de la actividad: Origen de los nombres. 2. Revisión del material didáctico del tema: Nombre sistemático IUPAC de alcanos (video) 3. Investigación y realización de mapa conceptual de: Nombres sistemáticos IUPAC de alcanos	Antes de clase: Revisa el material didáctico: Video de nombre sistemático IUPAC de alcanos Investiga en Google Scholar, Redalyc o SciELO: Nombres sistemáticos IUPAC de alcanos Organiza la información y elabora un mapa conceptual en miMind o Cmap Tools	Realiza la actividad: Origen de los nombres	PCK
				TCK	
				PCK	
				TPK	
	Orientación de la atención	Indica los objetivos de la clase. Proporciona instrucción a través de Mini-lección: Origen de los nombres		Realiza la actividad: Origen de los nombres	PCK
Desarrollo	Interacción personal	Integra equipos cooperativos de tres miembros y solicita realización de actividades: 1. Integración de: mapa conceptual de nombres sistemáticos de alcanos (lineales, ramificados y cíclicos) 2. Serie de ejercicios: nombre IUPAC de alcanos simples a través de la estrategia rompecabezas	Durante clase: Contesta la serie de ejercicios: Nombre IUPAC de alcanos simples (Rompecabezas) usando Reunión en Teams, Trello y Forms de Teams Elabora informe escrito cooperativo de Nomenclatura IUPAC de alcanos en Trello Elabora un cuadro PNI del tema Nomenclatura IUPAC de alcanos en Trello	Integra un mapa conceptual de los nombres sistemáticos de alcanos (lineales, ramificados y cíclicos) en miMind	TCK PCK
				PCK	
	Procesamiento de la información	Expone el tema: nomenclatura IUPAC de alcanos, a través de la clase sincrónica en Teams; solicita elaboración de notas y resolución de prueba objetiva: Fórmula estructural-nombre de alcanos I		Elabora notas, resuelve la prueba objetiva: Fórmula estructural-nombre de alcanos I en Forms de Teams	TCK, PCK

Aprendizaje cooperativo					Elemento del modelo TPACK (TCK, TPK, PCK) que más se asocia a la actividad*
			AI		
Fases	Momento	Actividades del docente		Actividades de los estudiantes	
Desarrollo	Recapitulación	Repasa el tema brindando preguntas y recibiendo respuestas, con la información de Origen de los nombres y Nomenclatura IUPAC de alcanos	Durante clase	Participa en la actividad: brindar preguntas recibir y respuestas, en la que contrasta información de Origen de los nombres y Nomenclatura IUPAC de alcanos a través de Teams	PCK, TPK
Cierre	Evaluación	Evalúa a través de una prueba objetiva: Fórmula estructural-nombre alcanos II		Contesta la serie de ejercicios: Nombre IUPAC de alcanos simples (Rompecabezas) usando Reunión en Teams, Trello y Forms de Teams	PCK
	SSMT Solicita la elaboración de informe escrito del tema: Nomenclatura IUPAC de alcanos Solicita elaboración de un cuadro PNI acerca del tema: Nomenclatura IUPAC de alcanos Solicita la resolución de la prueba objetiva: Fórmula estructural-nnombre III	Retroalimenta resolviendo los ejercicios de la prueba objetiva: Fórmula estructural-Nombre II		Elabora informe escrito cooperativo de Nomenclatura IUPAC de alcanos en Trello	PCK
				Elabora un cuadro PNI del tema Nomenclatura IUPAC de alcanos en Trello	
				PCK	
		Después de clase	Resuelve la prueba objetiva: Fórmula estructural-nombre III en Forms de Teams	PCK TCK	

AI = Aprendizaje invertido

IUPAC = International Union of Pure and Applied Chemistry

Nota: los equipos cooperativos estuvieron formados por tres integrantes durante cada sesión de clase.

* Se aclara que para diseñar cada actividad de la secuencia se contemplaron todos los componentes del modelo TPACK, sin embargo consideramos que los que se muestra en esta columna son los que tienen mayor implicación.

Fuente: elaboración propia.

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