Vol. 3 No. 6 (2025)

Journal of Social Signs Review

Online ISSN Print ISSN

3006-4651 3006-466X

Enhancing Organic Chemistry Education: The Impact of Simile-Based Drawings on Complex Theory Comprehension

[1*]Fawad Islam -Email- fawadislam9455@gmail.com
[2]Azam Tariq -Email- azamt6778@gmail.com
[3]Said Alam -Email- alambschemist@gmail.com
[4]Faria Mirza -Email- fariamirza4pak@gmail.com
[1*]College of Material, Chemistry & Chemical Engineering, Chengdu University of Technology China, 610059 Chengdu, China.
[2]School of Chemistry ENS Paris-Saclay 4 avenue des Sciences 91190 Gif-sur-Yvette, France.
[3]School of Environmental and Chemical Engineering, Jiangsu University of Science and Technology, 212000 Zhenjiang, China.
[4]College of Mathematical Sciences, Chengdu University of Technology China, Geomathematics Key Lab of Sichuan Province, Chengdu University of Technology, Chengdu, 610059, China.

Article Details:

Received on 16 May 2025
Accepted on 15 June 2025
Published on 18 June 2025

Corresponding Authors*:
*Fawad Islam

Abstract

Cognitive complexity of organic chemistry due to abstract reaction mechanism, three-dimensional molecular interactions and symbolic representation poses significant learning challenges to students. Novel instructional approach is proposed which involves incorporation of simile-based drawings as cognitive, visual scaffold to understand hard concepts including electrophilic aromatic substitution, stereochemical inversion, resonance delocalization. Based on the theory of Cognitive Load (CLT) and Dual Coding (DCT), the present approach explains how conceptual images can lessen extraneous cognitive load and promote germane processing through creation of non-trivial mental structures by learners. Transforming of abstract molecular behavior into simple analogies, like making comparisons between nitronium ions and butterflies buzzing around the electron-rich "nectar" of benzene rings or the SN2 stereochemical inversion to an umbrella inverting in the wind, the method functions to transfer complex chemical theory into related models of thought. Using field-based case studies and classroom-based examples, the study demonstrates that instructor-created combined with student-created illustrations do not only enhance retention and conceptual understanding of content, but also enhance engagement, a feeling of ownership, and multimodal learning. Regardless of the scope of the institutional barriers in the form of the inability to attract sufficient visual teaching resources and train educators, the results highlight a transformative potential of simile-based graphics as a scientifically informed, scalable, and inexpensive innovation to promote organic chemistry education.

Keywords: Organic Chemistry Education, Simile-Based Graphics, Cognitive Load Theory, Dual Coding Theory, Student Engagement, Complex Concept Simplification

Introduction

Scientific progress and technologies complement educational content with valuable additions, yet present complications in the course of students' learning processes, especially in subjects such as organic chemistry. This is true because most of the knowledge acquired by students in this discipline requires an understanding of reaction mechanisms, molecular spatial orientation, and electron behavior at molecular level, which requires high level of thinking. As *Derkach (2022)* underlines not only quantity but also quality issues, such as cognitive overload, may be a significant challenge in chemistry whenever problem-solving involves far more than repetitions of the information provided. This issue becomes more complex when the instructional tools that are used in teaching do not meet the cognitive complexity of the students thereby leading to low understanding and enactment *(Sibomana, L et al., 2020), (Fontana, J., 2020).*

To these challenges, Cognitive Load Theory (CLT), developed by Sweller in 2020 offers guidelines for designing instructions since it classify cognitive load into intrinsic, extraneous and germane load. Conductive load depends on the complexity of content, where in organic chemistry it is the structure of molecular and sequence in the mechanisms of the reactions *(Ali, Ullah, & Raees, 2023).* Extraneous load, however, originates from designed information; appropriate layout may generate new cognitive demands which distort the main learning goals *(Urbano & Caballes, 2020; Eitel et al., 2020).* However, the germane load refers to the effort used in constructing meaningful content and schema that can be used in knowledge acquisition and application *(Ghanbari et al., 2020).*

Along with the Cognitive Load Theory (CLT), there are such similar and complementary theories that explain the system of knowledge absorption by the students in complex issues of science as Dual Coding Theory (DCT) that is proposed by *Allan Paivio.* According to DCT, simultaneous presentation of verbal and visual information increases learning; which can be achieved when the learner can develop linked mental representations using two parallel channels of cognition. In organic chemistry, the understanding of some of the concepts can be enhanced by blending visual analogies into the description of the concepts in the form of an illustration, such as a simile-based drawing that creates conceptual understanding and remembering by anchoring abstract concepts in both linguistic and pictorial forms.

Minimization of the extraneous load is essential most especially in organic chemistry where students are required to deal with very many in shutdowns of information and several modeling. Combining simile-based drawings and metaphors in chemistry learning is a good strategy towards the reduction of this burden since they give real representation of the abstract nature of matter *(Williams et al., 2021).* For example, it is easier to explain a reaction mechanism or stereochemistry using such visual representations particularly through the creation of mental schemas to augment the germane load processing espoused by CLT. For instance, the illustration of the use of the phrases based on similes and metaphors which makes it easier to explain complex issues can be considered through the lessons in electrophilic aromatic substitution or stereochemical inversion regarding to the mechanisms concerning.

Computer-supported striking and virtual reality has also been suggested to be used in chemistry learning as cognitive tools to enhance the learning experiences of learners through other modes *(Keller et al., 2021; Peeters et al., 2023).* Such tools have been shown to have the capacity of reducing the extraneous load because of affordances given new environments to interact with molecular structures, there by refreshing their mental models of the chemical reactions *(Jankowski et al., 2020)*. Nonetheless, a more basic type of drawing, such as the simile-based drawings are plausible and effective because they can be done with simple implements, which can also be integrated into mainstream curriculum.

In this paper, consider how drawings that use similes can improve cognitive load management in organic chemistry learning about reaction mechanisms and stereochemistry in particular. As with electrophilic aromatic substitution or even the formation of coordination complexes, most of these topics can be presented with comprehensible analogies such as a butterfly (NO_2^+) being attracted to the "nectar" of benzene. The next two sections provide specific examples of the use of simile-based visuals in chemistry instruction, along with a discussion of how metaphors and even rough sketches can reduce cognitive load and facilitate student understanding of this particular discipline.

Theoretical Foundations

Cognitive Load Theory (CLT) in Educational Practice

Cognitive Load Theory (CLT) offers a conceptual background to better understand how learners interpret complicated information according to the nature of the discipline in which they are studying, in this case, organic chemistry. CLT assumes that human working memory capacity is also limited, and can be very quickly overloaded when processing novel and complex information *(Sweller et al., 2023)*. *Sweller (2023)* also underlines that curriculum should be planned to control load diligently; that is, working memory load and to support working memory to construct long-term memory schemas; especially in those domains where loads of attention are needed.

Intrinsic Cognitive Load

Intrinsic cognitive load is as a result of the inherent complexity level of the content; and more often in organic chemistry, concepts like electron movement, stereochemical arrangements, and resonance configurations are complex *(Maj, 2020)*. Molecular processes need to be understood by the organic chemistry students and this entails a lot of visualization of abstract interactions that are cognitively demanding especially for first-time learners *(Duran, Zavgorodniaia, & Sorva, 2022)*. For instance, the students require mental schemas for electron density distribution and how these dictate the reactivity of molecules this is vital but semantically complex (Timothy et al., 2023). For the first-years, these concepts can be especially challenging because they do not possess the appropriate cognitive schemas to handle such a wealth of information *(Martella et al., 2024)*. Thus, m Compute Intrinsic Load stands out as a critical approach to making the material less demanding to learn and understand by offering practical strategies for resolving the noted cognitive obstacles in organic chemistry.

Extraneous Cognitive Load

Unnecessary cognitive load results from the design of instructions that are irrelevant or may in fact interfere with learning. Complex diagrams or unwell-organized instructional schemata play an essential role in determining the extraneous load common to organic chemistry course *(Jordan, Wagner, et al., 2020)*. These factors add extra cognitive loads because students have to attend to factors unrelated to learning points, resulting in an overload of working memory and dis engagement *(Casey et al., 2023)*. Instructional design should thus endeavor to reduce extraneous load by reducing the amount of extraneous information supplied to students, by remaining as close to subject concepts, and steering clear of all the other potential sources of interference *(Lespiau & Tricot, 2024)*. For instance, *Appel, Kärcher, and Körner (2023)* using eye-tracking glasses found that students are more engaged and comprehend better if the instructions are designed to reduce the complexity of displayed visuals and guide attention towards selected reaction schemes *(Appel et al., 2023)*.

Germane Cognitive Load

On the other hand, germane cognitive load entails the mental effort that facilitate learning and elaboration of schemas. Emerging from it is the ability that is involved with building and elaborating on the knowledge representations in mind, which is important for effective learning of topics that may be difficult to grasp as are the organic chemistry topics as found out by *Anthony J et al., 2008)*. To increase germane load instructors can use graphic organizers for simplifying information presented during the lesson, thus helping learners organize the new information in terms of their existing mental schemas *(Quintero-Manes & Vieira, 2024)*. For instance, employing symbols and concrete images in the form of simplified models and simile-based drawings to reaction mechanisms helps in building up the schema as it gives students the crude real-life analogies of the core concepts *(Jordan, 2024)*. According to Timothy *et al. (2023)*, schema-based methods are especially useful in STEM fields because knowledge is built in sequences which are layered into students' long-term memory and integrate into them new data.

Application of CLT in Organic Chemistry

The major idea that is instilled in educational practice by CLT is to use instructional techniques that minimize extraneous load so as to maximize the values of intrinsic and germane loads to warrant enhanced learning *(Maj, 2020)*. Some design strategies are the simplification of representations, the use of modules that organize support material according to the learning tasks, and the use of helpful metaphors *(Ali et al., 2023)*. For example, designing visuals that employ a figure of speech such as simile helped to reduce cognitive load by limiting the scope of what students had to understand in organic chemistry to relevant mechanisms rather than peripheral elements, *(Duran et al., 2022)*. This paper examines the approach of such instructional practices consistent with CLT to diminish cognitive load and enhance intake of material applied on organic chemistry education. Through management of these cognitive loads, the educators create deeper learning and understanding of the content as students are blessed with the right tools for the processing and storage of complex concepts in organic chemistry *(Sozio et al., 2024)*.

Dual Coding Theory (DCT) and Multi-Sensory Learning

According to Dual Coding Theory (DCT) developed by Allan Paivio, learning takes place when two types of information, verbal and visual, are processed simultaneously because these two sets of information pass through different but interacting systems in the brain *(Sweller, 2020)*. Hence, through the use of the verbal and pictorial modal, the DCT affords the learners to encode and retrieve information with the use of multiple cognitive units enhancing learning comprehension and recall *(Zhao, 2023)*. This approach is particularly useful in areas such as organic chemistry where coping with concepts as well as applying information within the learner's brain is paramount difficult *(Bahari, 2023)*.

In chemistry in particular, DCT facilitates learning using texts and other graphical display in as a principle to enhance learning. The use of words and diagrams means that instructors can provide students with more routes into such information thus helping

Vol. 3 No. 6 (2025)

Journal of Social Signs Review

Online ISSN 3006-4651

Print ISSN 3006-466X

them construct schemata. The analysis of previous work has identified positive effects of using both illustration and written description, as it lowers the amount of mental work needed to grasp it *(Boonchutima et al., 2023)*. For example, *Braun and colleagues (2022)* point out that molecular drawings and descriptions must be read with annotations, as these would foster the learners' ability to construct and recall mental representations of the structures of chemicals.

DCT also holds that gesture together with oral instructions should be used when teaching concepts such as organic reactions. In the instructional design study, *Timothy et al. (2023)* affirmed that it is more profound when learners are exposed to the content with both pictures and texts with concerns to reaction mechanisms and spatial transformations. These findings align with DCT's core premise: It has been found, as *Chang et al. (2024)* posit, that the integration of visible and spoken words has been found to facilitate students' information processing, encoding and recall. It entails multiple channeling to imply such kind of idea that means the ability of students to grasp information through different sensory inputs contributes to enhance their mental models of particular chemical processes *(Qin et al., 2024)*.

However, DCT has continued to be advanced in recent years by technology-enhanced methods that have enhanced the application of DCT in teaching chemistry. For instance, by using and creating new interactive means such as models on computers students are allowed to get hands on experience in how the molecules interact deepening on their knowledge *(Jankowski et al., 2020)*. Physical models and augmented reality tools also allow to provide students with the ability to study molecular dynamics and their visual practice in real time, which highlights how DCT principles can be applied in current conditions.

Integrating DCT techniques into the course design, especially, when it is difficult to explain, for instance, organic chemistry, can aid tutors in controlling the cognitive load since essential information will be conveyed by both the verbal and visual elements. This approach was found to be related to CLT because it minimizes the extraneous load and improves germane processes, leading to a better learning experience *(Bahari, 2023)*. Chemistry educators need to use fewer illustrations, make content interactive by engaging students with educational multimedia and diversify the way they describe concepts.

Applications of Simple Drawings in Organic Chemistry

Electrophilic Aromatic Substitution (EAS): Case Study in Nitration of Benzene

Electrophilic Aromatic Substitution (EAS) is one of the basics in Organic Chemistry, specifically significant in illustrating how electrophiles work in aromatic structures such as benzene. A key role is given to the concept of the visual simplicity, especially if some reactions require simpler representations. A simile can help: as for the nitronium ion (NO_2^+), it is possible to qualify it as a "butterfly" which flies to the 'honey', which in this case is the benzene ring the symbol of the π-electron cloud. This assists in creating a pictorial mental image of how EAS happens to visualize the interaction between the electrophile and the electron rich nature of benzene, as is with the work of Wu et al. (2023) on the control of electrophile in aromatic nitration.

Formation of the Electrophile

The EAS process involves formation of the electrophile this is, NO_2^+, this is generated through the reaction of H_2SO_4 and HNO_3. It pointed out that nitric acid and sulfuric acids form nitronium ion after the elimination of water *(Domingo et al., 2021)*. Such diagrams explain the movement of the electrons as well as the bonding, and then make the pupils understand the aspect that 'fell' on NO_2^+ and how it gets prepared for attack. Using downward arrows directing to the movement of electrons we avoid extra interference in working memory and share with the learner a clear sight of this pre-nitration phase without loading his working memory *(Nakatani et al., 2022)*.

Electrophilic Attack on the Benzene Ring

Subsequently, the nitronium ion which is refer to as the butterfly comes closer to the described flower that is benzene ring which is composed from delocalized π-electrons. This stage is important as, it is at this stage that electron density is transferred from benzene ring to the electrophile. It is equally possible to see from the simplified representation of π-electrons shifting towards NO_2^+, thus destabilizing benzene ring for some time, which is a requirement if the reaction is to take place. This is usually the stage that students can understand why benzene has electron density, which makes it reactive to electrophiles This conforms to electron attraction and density that is essential in studies in organic reactivity *(Eckert et al., 2020)*.

Formation of the Arenium Ion Intermediate

After the first approach, the benzene ring forms sigma complex called the arenium ion which is stabilized by resonance for a short period. This intermediate structure can be presented with a number of resonance structures which show the electron mobility around the benzene ring. Curved arrows depict relocating electron pairs which represent the transient exchange view of electrons to stabilize the interim *(Blum et al., 2021)*. This visual analysis helps the students to differentiate between resonance as a kind of stabilization as well as observe the place of resonance in interaction middlemen without considering complicated theoretical variables.

Restoration of Aromaticity

In the last stage, the aerial proton is removed from the arenium ion and the unique stability of the benzene ring is again that of nitrobenzene. An interface conclusion that depicts the reforming of a proton reconstitutes benzene's resonance-stable structure completes the reaction cycle. Through couching this step as a 'return to stability', students are able to understand the more unique stability of the aromatic ring, thereby viewing this process as cyclic where each played part facilitates the entirety of the reaction (*Wu et al., 2023*).

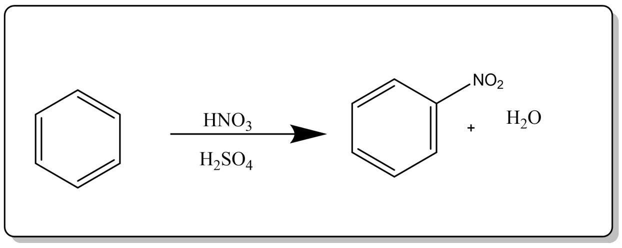

Figure: 1 General Reaction of Nitration of Benzene

By developing this set of straightforward, metaphorical illustrations, the EAS mechanism in benzene nitration appears more comprehensible. Using metaphors and stepwise images enhances the schema formation and decreases the amount of working memory load, as it has been done with simpler illustrations in the study of *Chi et al. (2024)* on cognitive value of diagrams in the organic chemistry instruction. Through these similarities and pictures, the students can learn all aspects of EAS and this way, enhances their learning and their ability to actually understand the subject.

Vol. 3 No. 6 (2025)

Journal of Social Signs Review

Online ISSN 3006-4651
Print ISSN 3006-466X

Stereochemistry and Inversion in SN2 Reactions: Case Study of (R)-1-Bromo-1-Phenylethane and Hydroxide Ion

In bimolecular nucleophilic substitution (SN2) reactions, stereochemistry is very important when analyzing molecular interactions in organic chemistry. SN2 mechanisms can be described as the direct transfer of an electron pair to a substrate causing the replacement of a leaving group due to the inversion of the steric configuration around the reaction center. Many of the roles, movements or processes are spatial and thus their explication and description can be quite complex; use of visual aids and metaphors can aid in this. For instance, the inversion of configuration in an SN2 reaction can best be illustrated to an umbrella flipping inside-out under conditions of strong winds; it will easily give a picture of the nucleophile 'shoving' the substituent across to the other side.

Selecting a Suitable Substrate: (R)-1-Bromo-1-Phenylethane

Stereochemical inversion is most easily demonstrated in to SN2 reactions where chiral substrates are employed such that inversion can be detected using (R)-1-bromo-1-phenylethane or (R)-2-bromobutane as opposed to bromoethane. These chiral compounds enhance the students' understanding of the inversion mechanism due to visibility of the stereochemical change in a product configuration *(Bocus et al., 2022)*. This substitution also helps to explain that only substrates where stereochemical results are observed should be selected for easier visualization of the effects of nucleophilic substitution by students.

Step-by-Step Visualization of the SN2 Mechanism

Nucleophile Approach and Backside Attack

The SN2 mechanism begins with nucleophile, here it is hydroxide ion (OH^-) approaching the substrate from the side opposite to the leaving group, bromine. This is a common methodology known as the backside attack which is necessary if the stereochemistry is going to be inverted and the nucleophile will have an impulse to knock the leaving group out. Additional visuals illustrating the orientation of the hydroxide with respect to the chiral carbon from the side opposite the leaving group are useful here. This setup is similar to the 'umbrella' analogy, the force exerted by the nucleophile inverts an affected molecule, the same way strong wind flips an umbrella *(Kiliclar et al., 2021)*.

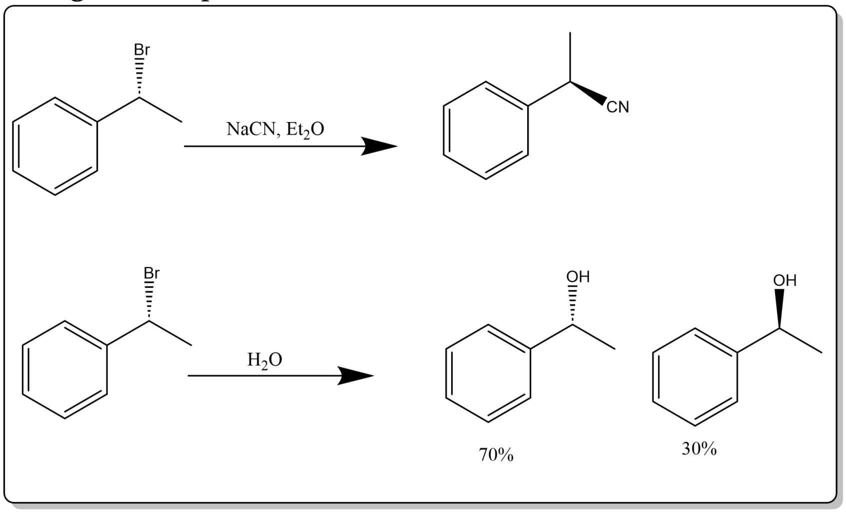

Figure: 2 Case Study of (R)-1-Bromo-1-Phenylethane and Hydroxide Ion

Transition State Representation

In the transition state of an SN2 reaction the nucleophilic and the leaving group of the substrate are only partially bonded to the central carbon, and that is why SN2 transition state is highly energetic and therefore unstable. Students are able to visualize this temporary structure by using two dashes connected by an arrow. The representation of partial bonds between the nucleophile, carbon and the leaving group enhance the understanding that both groups are only temporarily attached to the same carbon during inversion. To help students grasp why the SN2 pathway gives rise to stereochemical inversion, Dr. Li and his co-authors have employed a concept that could be described as a sort of "umbrella inverting": a manner of visualizing the energy dynamics of the mechanism *(Li et al., 2023)*.

Inversion of Configuration: Walden Inversion

The geometry of the reaction center is turned around completely when nucleophile coordinates and the leaving group evacuates. This stereochemical shift is known as the 'Walden inversion' in which the configuration of chiral carbon from original one (for example, from R to S). The use of simple drawings to depict transition of the initial (R)-1-bromo-1-phenylethane to the (S)-1-phenymethanol greatly helps to grasp inversion in terms of spatial relations. The visualization aids in understanding the "umbrella inversion" of the nucleophile in which this normally passive piece of the reaction has reversed the configuration *(Li et al., 2021)*.

These graphical illustrations help students to dissect the SN2 mechanism into easy to do stages while helping them appreciate the spatial and stereochemical implications of the phase. *Nesterov et al., (2021)* has shown that use of visual aids in teaching SN2 mechanisms do not only decrease the cognitive load, but also improve the students' ability to learn about the stereochemistry mechanisms by presenting the information in easily understandable sequential visuals. Further, amplifying the inversion metaphorical representation as a 'reversal under pressure' which is similar to conversion of an umbrella helps student to deliver an understandable mental representation according to the cognitive load theory and hence helping students to reinforce their conceptual knowledge about the topic of nucleophilic substitution *(Mosiagin et al., 2023)*.

Resonance and Electron Delocalization in Benzene: Case Study in Resonance Structures

The idea of resonance plays a pivotal part when considering the stability of special compound structures such as benzene. In benzene, the carbon atoms are not doubly bonded and therefore are not limited to having equal electron density in between them because of electron sharing, which can perhaps explain for this kind of structure's stability. Nevertheless, the traditional theory of resonance, which is usually explained through line drawings, may rather remain an abstract concept for learners. To help for better understanding, resonance can be described prosaically, as a kind of an endless "wave" circulating around the benzene ring as a symbol of electrons movement and overlapping. *Kazim et al., (2023)* Of course this analogy with the electrons of benzene where they are not located on the particular bonds but evenly distributed in the ring to balance the molecule so to speak.

Using Simple Drawings to Teach Resonance in Benzene

Individual Resonance Structures: Electron Movement as a "Wave"

With conventional benzene diagrams, single and double bonds are drawn to indicate that the electrons are moving or swapping over the bonds. This movement can be also described as circular one of electrons and additionally have a waved like form to describe the change of the resonance structures. This beach of a metaphor assists in defining it to students in terms that some of the electrons are not immobile but are all participating in the relative stability of the ring network *(Capobianco et al., 2021)*. While introducing this concept, there should be curved arrows pointing at electron flow; this kind of depiction is helpful in the learners' understanding of resonance as a signal flow instead of an electronic circuit *(Yu et al., 2022)*.

Resonance Hybrid Representation: The "Wave" in Continuous Motion

The real structure of benzene is probably the structural formula which is also called the resonance hybrid since it prevents the representation of electrons within the plane as localized double bonds. That is why a dashed circle to illustrate the extent of electron delocalization in the ring is used because electron density in benzene is evenly distributed. But when Townsend introduces the idea of this 'wave' with regards to the resonance hybrid, the piece de resistance of benzene is presented not as shifting double bonds, but as a perpetually circulating electrons round the ring. This visual may help consumers understand that it is this electron delocalization which gives benzene stability and not different forms of resonance as it is presented by *Stamenković et al., (2021)*.

Implications for Stability and Reactivity: Understanding Benzene's Preference for Substitution Over Addition

Stability is another form of Benzene where its resonance aids in its production; Benzene trade favorably substitution cases with addition cases; the latter would destroy other electron-delocalized structures. Describing resonance structures in class and comparing them with addition reactions in alkenes allows for recognizing that the delocalized 'wave' of electrons in benzene does not interfere with the aromatic stability during substitution reactions because the whole wave remains in place *(Ueno et al., 2021)*. The enhancement of the visualization of resonance through a protective wave that cannot be changed by addition also strengthens the understanding of benzene's functionality and curated choice of reactions.

These approaches help to minimize cognitive load and combine abstract concepts into understandable and comprehensible visuals as a single "wave" of electron. Such metaphors are congruent with CLT and help enhance several mental models of resonance, which are crucial for students to grasp about aromatic stability *(Chugunova et al., 2020)*. Employing understandable relativity such as a continuous wave they get good grounds to explain resonance thus enhancing the understanding of the electron distribution in the benzenes.

Enhancing Learning Outcomes Through Visual Aids

Incorporation of visual teaching aids is crucial so as to help facilitate improved comprehension of students on the various concepts in organic chemistry especially those supported by multi modal teaching learning instruments. Studies have attributed the use of visual, touch, and interactive aspects in instructional enunciative designs as greatly augmenting student interest, understanding and learning of organic chemistry *(Gao et al., 2024)*

The Role of Metaphors in Teaching Organic Chemistry

In this paper, it is established that metaphor as a tool for teaching-learning in education cannot be overemphasized especially in difficult areas of learning like Organism Chemistry. Metaphorical teaching therefore works not only in reaching out to the students but also in unraveling complex concepts by making what might sound complex to become concrete reality. Studies show that proper choices of metaphor can help downplay students' concerns over certain subject matters and develop an otherwise latent curiosity. For example, stress that choosing right managerial metaphors for students can help improve the connection between scientific thought and the real world *(Francom and Saitta, 2024)*.

Simile Examples in Organic Chemistry Instruction

Example 1: Conformation of Ethane

Posted through the recall of human postures, the ethane conformation can easily be explained and made to be understood. Like people may perform thousands of movements when they are walking, ethane may have fifty different conformations. Of these, the staggered conformation which is akin to a relaxed posture is the most stabilized one. Besides modifying the idea of molecular conformations into understanding that is easier for students to comprehend, the analogy helps students visualize and comprehend stability of structures that are related to ethane (Weinhold, 2003).

Example 2: Stability of Double Bonds in Diolefins

In explaining the differences among cumulative, conjugated and isolated diolefins when talking about the stability of the carbon-carbon double bond, one can say "distance produces beauty". Diolefins with double bonds between two carbon atoms are cumulative and are described as having "two tigers in one mountain," which is sign of instability. Conjugated diolefins, where the double link is separated by a single bond, illustrates stability in synergistic cooperation akin to 'two war horses at once.' Such representations also make learning easier to grasp since abstract concepts can be better understood when compared to easier concepts with them *(El-Nahass et al., 2024)*.

Example 3: Additions to 1,3-Butadiene

The process of the electrophilic addition of HBr to 1,3-butadiene is another case that allows the application of a metaphorical teaching. The reaction mechanism can be described as the scenario where one moves a ball across the sloped surface; the stability of the resultant intermediates being equivalent to the steepness of the slope. At lower temperatures, there is a preference of the 1,2-addition following the movement of the ball rolling on a relatively inclined plane and the formation of a considerably stable intermediate product. On the other hand, the retention of the 1,4-addduct product is enhanced by increased energy allowing the ball to overcome steeper slope at higher temperature. It provides students with the point of reference in order to understand the meaning of thermodynamic and kinetic concepts and to promote a better understanding of reaction dynamics *(Yang et al., 2023)*

Benefits of Multi-Sensory Learning with Simple Drawings

Organic chemistry education benefits greatly from habitually using multiple means of learning that simultaneously appeal to at least two senses, visual, touch/feel, and auditory. *Carle (2020)* points out that when teaching reaction mechanisms, new concepts previously considered abstract and intricate, are easier to grasp when aided by manipulatives. For example, use of digital hybrid illustrations enables students interact with molecular structures in a dynamic manner enhancing their capacity to understand reaction informative mechanisms *(Sedlar et al., 2023)*.

Other Kit has also been identified to enhance application of Virtual Reality (VR) and Augmented Reality (AR) to enhance learning of organic chemistry. *Ramírez and Bueno (2020)* noted that students are able to teach the concepts in the VR environments while interacting with the molecular structures, thus effectively improving on spatial skills, and at the same time, minimizing on the cognitive load. Likewise, the sequential drawing activity facilitates a student's understanding of resonance structures as noted in works where students have made progress working through guided molecule drawings *(Braun et al., 2022)*. There is also the use of computer animations and movements, which alongside the physical events, such as hand movements, enable the student to associate the chemical concepts with the physical movements and, therefore, enhance his or her understanding *(Ping et al., 2021).*

Student-Created Visuals: Promoting Engagement and Ownership

Visuals made by students make learners more involved in the learning process, and make them feel that they are the ones responsible for comprehending what has been taught. The study by *Cha et al. (2021)* explored the effects of teaching using comics drawn on the topic of organic chemistry students who produced their own comics of the reaction mechanisms cited that they have improved understanding of the content and its relevance. Likewise, *Gupte et al. (2021)* conducted research on attained writing-that-learns activities in organic chemistry and found out that writing activities like having students draw structures of their own improved meaningful learning experiences.

Creating virtual experiments or adopting inquiry-based visual creation exercise students can relate theories to practice, as mentioned in the work by *Mistry and Shahid (2021)*. Furthermore, scaffolded synthesis skills exercises in which students envision synthesis routes on their own practice problem-solving techniques that are higher order and embed a unified theory of synthesis strategies as applied in organic chemistry *(Flynn, 2021).*

Visual-Based Assessment: Gauging Conceptual Understanding

Visual based or conceptually based assessments offer insights other than the standard method of assessing student's knowledge or skills. Fontana (2020) investigated gamification of ChemDraw in which students' learning and performance in the program were determined by their ability to create and analyze chemical structures through computer-based games. It also enhanced the skills of traditional technical drawings and enabled the teachers to evaluate student recognition of structural relations.

Gallegos et al. (2021) complement this by showing that molecular representations help students understand better by enabling them to envision the progression of an organic reaction. Engineering complex natural product synthesis reinforced through computational planning poses students to applied synthesis problems whereby overall subject content can be effectively judged visually *(Mikulak-Klucznik et al., 2020).* Approaches like the multiple object property representations, as expounded by *Tatiya et al (2023),* advocate for the use of tow way interactive tasks to measure comprehension, incorporating all the more senses and therefore affording a very good coverage of a good measure of metisise in organic chemistry.

Challenges in Implementing Simple Drawings and Proposed Solutions

Although the use of visual aids and multi-sensory teaching and learning resources in large measure enhance the teaching of organic chemistry, there is a list of challenges that hinders their use. Such challenges are, for instance, limited awareness of how to make visual supports understandable and the lack of proper organizational funding for pictures.

Teacher Proficiency and Training

The other supplemental outcomes indicate that for the MM teaching genre, teacher knowledge of when and how to create and employ graphics is particularly crucial. According to *Zotos et al., 2021;* Organic chemistry teachers have no adequate training on how to teach detailed reaction mechanisms in simple, easy to understand illustrations. The kind of training that *Greenaway and Jelfs (2021)* have suggested is to integrate computational and experimental training processes that will help the trainers learn about applicable computational knowledge in the trainers' processes.

Furthermore, research done showed that when teachers were assigned to use comics as good teaching tools, the credibility of other teaching concerning the use of intriguing visual aids increased *(Cha et al., 2021)*. These programs also assist in preparing the educators for Machine learning applications for instance reaction predictions in order to present complicated concepts to the students in tandem with the lesson they are teaching their students. Such competencies would enable teachers cultivate visual things as core teaching and learning tools; thus, improve students learning outcomes in organic chemistry.

Institutional Support and Resource Allocation

Effective approaches to give to multi-sensory and visual learning for the organic chemistry classes include getting institutional support and resources. In their study based on Virtual Inquiry-Based Chemistry Experiments, *Mistry and Shahid (2021)* also pointed out that there is potential lack of flexibility in terms of the digital support resources where elements like virtual labs and simulation software are required to enhance gadgets. In a similar vein, *(Voinarovska et al., 2023)* established that deep learning models, which can be used in the context of reaction outcomes' forecasting, enjoy greater performance when supported by specific institutional computing infrastructure.

In addition, *Gallegos et al., (2024)* pointed out that predicting reaction yields using machine learning applications, in the area of organic chemistry, is extremely computationally intensive and that many academic institutions are severely under resourced. Better resource organization, including instructional instruments and development programs, could help institutions make visual learning a part of the curriculum *((Mikolajczyk et al., 2023)*. Also, Fontana notes that tools such as ChemDraw offer great promise as a useful tool in distance education but such software, and the license for it must be purchased and the instructors must be trained how to use the program to its full potential in the distance learning environment.

Limitations and Future Directions

The application of simile-based drawings has shown tremendous promise in improving the comprehension of complex organic chemistry concepts by students, but there are a number of limitations which have to be recognized. To begin with, the research is most based on qualitative interpretations and representative case studies as opposed to empirical data in the classroom or controlled experimental confirmation. Generalizability and statistical robustness of the results would have been low because of the lack of quantitative performance measures, e.g. pre- and post-intervention testing. Moreover, visuals created using metaphors might also not work so effectively in a variety of cases because of the previous experience of students, cognitive preferences or linguistic or cultural acquaintance with the selected metaphors.

The other limitation is the fact that the skills and capacity of educators to create and develop effective visual metaphors is not standardized since most of them might not have been trained in visual pedagogy or might be unprone to available illustrative materials. Practical hindrances to the application of such instructional strategies at scale are largely due to institutional limitations in regard to the time and space available in the curriculum (class time, overstuffed syllabus), as well as the digital infrastructure available.

Further studies ought to involve empirical classroom-based studies studying learning outcome through simile-based visual intervention within various learning settings. It would be much more evident of the cognitive and pedagogical impact of the metaphor-enhanced instruction and the traditional instructions to conduct comparative studies using controlled designs. Furthermore, a broader implementation could be facilitated by developing teacher training modules and a fixed set of visual toolkits. There is also a possibility to explore the exploitation of new technologies like interactivity of animations, augmented reality, and images generated by AI which can also provide new directions to enhance multimodal learning in organic chemistry.

Conclusion

The use of simile-based visuals does enhance cognitive load management when explaining challenging concepts in organic chemistry like electrophilic substitution, resonance and stereo chemistry to the students. These visual aids are thus are developed based on Cognitive Load Theory which enable the students to reduce the extraneous load and allow for the germane load processing in order for the students to be able to focus on the content rather than get distracted by seemingly irrelevant content. Linguistic relatability improves the structure by enriching it with a multi-sensory encoding and retrieval process. These selective visual and metaphorical approaches contribute to the construction of strong mental representations of the content which benefits learners in the ways of understanding, memorizing and paying attention. Eliminating organizational constraints such as trainer capacity and available training materials is going to be key to reap the full potential of this teaching approach and guarantee long-term positive impacts on students understanding of organic chemistry and other advanced courses.

Disclosure Statement

The authors declare that they have no known competing financial interest.

References

Ali, N., Ullah, S., Raees, M. (2023), The effect of task specific aids on students' performance and minimization of cognitive load in a virtual reality chemistry laboratory, *Computer Animation Virtual Worlds; 34*(6), e2194.

Anthony Jr, R. (2008), Cognitive load theory and the role of learner experience: An abbreviated review for educational practitioners, *AACE Review; 16*(4), 425-439.

Appel, T., Kärcher, K., & Körner, H.-D. (2023), *Investigating Cognitive Load for Tasks with Mathematics and Chemistry Context through Eye Tracking;* Paper presented at the Proceedings of the 2023 Symposium on Eye Tracking Research and Applications.

Bahari, A. (2023), Challenges and affordances of cognitive load management in technology-assisted language learning: A systematic review, *International Journal of Human–Computer Interaction; 39*(1), 85-100.

Blum, S. P., Nickel, C., Schäffer, L., Karakaya, T., & Waldvogel, S. R. (2021), Electrochemical nitration with nitrite, *ChemSusChem; 14*(22), 4936-4940.

Bocus, M., Vanduyfhuys, L., De Proft, F., Weckhuysen, B. M., & Van Speybroeck, V. (2022), Mechanistic characterization of zeolite-catalyzed aromatic electrophilic substitution at realistic operating conditions, *Jacs Au; 2*(2), 502-514.

Boonchutima, S., Chongkolrattanaporn, T., & Kongchan, W. (2023), *Cognitive Load Theory in Online Education: Leveraging Interactive Media, Testing, Interaction and to*

Enhance Engagement and Active Learning; Paper presented at the TENCON 2023-2023 IEEE Region 10 Conference (TENCON).
Braun, I., Langner, A., & Graulich, N. (2022), *Let's draw molecules: Students' sequential drawing processes of resonance structures in organic chemistry;* Paper presented at the Frontiers in Education.
Capobianco, A., Landi, A., & Peluso, A. (2021), Is Aromatic Nitration Spin Density Driven, *Chemistry; 3*(4), 1286-1301.
Carle, M. S., & Flynn, A. B. (2020), Essential learning outcomes for delocalization (resonance) concepts: How are they taught, practiced, and assessed in organic chemistry, *Chemistry Education Research Practice; 21*(2), 622-637.
Casey, J. R., Supriya, K., Shaked, S., Caram, J. R., Russell, A., & Courey, A. J. (2023), Participation in a High-Structure General Chemistry Course Increases Student Sense of Belonging and Persistence to Organic Chemistry, *Journal of chemical education; 100*(8), 2860-2872.
Cha, J., Kim, H. B., Kan, S.-Y., Foo, W. Y., Low, X. Y., Ow, J. Y., Chia, P. W. (2021a), Integrating organic chemical-based socio-scientific issues comics into chemistry classroom: expanding chemists' toolbox, *Green Chemistry Letters Reviews; 14*(4), 689-699.
Cha, J., Kim, H. B., Kan, S.-Y., Foo, W. Y., Low, X. Y., Ow, J. Y., Chia, P. W. (2021b), Integrating organic chemical-based socio-scientific issues comics into chemistry classroom: expanding chemists' toolbox, *Green Chemistry Letters Reviews; 14*(4), 689-699.
Chang, H.-Y., Chang, Y.-J., & Tsai, M.-J. (2024), Strategies and difficulties during students' construction of data visualizations, *International Journal of STEM Education; 11*(1), 11.
Chi, B. K., Gavin, S. J., Ahern, B. N., Peperni, N., Monfette, S., & Weix, D. J. (2024). Sulfone Electrophiles in Cross-Electrophile Coupling: Nickel-Catalyzed Difluoromethylation of Aryl Bromides, *ACS catalysis, 14*(14), 11087-11100.
Chugunova, E., Frenna, V., Consiglio, G., Micheletti, G., Boga, C., Akylbekov, N., Spinelli, D. (2020), On the nucleophilic reactivity of 4, 6-dichloro-5-nitrobenzofuroxan with some aliphatic and aromatic amines: selective nucleophilic substitution, *The Journal of Organic Chemistry, 85*(21), 13472-13480.
Derkach, T. M. (2022), *ICT-based assessment of cognitive load in chemistry learning,* Paper presented at the Journal of Physics: Conference Series.
Domingo, L. R., Seif, A., Mazarei, E., Zahedi, E., & Ahmadi, T. S. (2021), Quasi-RRHO approximation and DFT study for understanding the mechanism and kinetics of nitration reaction of benzonitrile with nitronium ion, *Computational Theoretical Chemistry; 1199*, 113209.
Duran, R., Zavgorodniaia, A., & Sorva, J. (2022), Cognitive load theory in computing education research: A review, *ACM Transactions on Computing Education, 22*(4), 1-27.
Eckert, T., Harmeyer, G., Legate, S., & Mathe, S. (2020), A Rationale for the Ortho Effect in Electrophilic Aromatic Substitutions, *Letters in Organic Chemistry, 17*(9), 655-658.
Eitel, A., Endres, T., & Renkl, A. (2020), Self-management as a bridge between cognitive load and self-regulated learning: The illustrative case of seductive details, *Educational Psychology Review, 32*(4), 1073-1087.

El-Nahass, M. N., Fayed, T. A., El-Gamil, M. M., & Fouda, A. E.-A. S. (2024), Synergistic inhibition effect of diolefinic dye and silver nanoparticles for carbon steel corrosion in hydrochloric acid solution, *BMC chemistry, 18*(1), 193.

Flynn, A. B. (2021), Scaffolding Synthesis Skills in Organic Chemistry.

Fontana, M. T. (2020), Gamification of ChemDraw during the COVID-19 pandemic: investigating how a serious, educational-game tournament (molecule madness) impacts student wellness and organic chemistry skills while distance learning, *Journal of chemical education, 97*(9), 3358-3368.

Francom, E. R., & Saitta, E. K. (2024), Speaking of Organic Chemistry: A Faculty Metaphor Analysis in Organic Chemistry Education, *College Teaching*, 1-9.

Gallegos, L. C., Luchini, G., St. John, P. C., Kim, S., & Paton, R. S. (2021), Importance of engineered and learned molecular representations in predicting organic reactivity, selectivity, and chemical properties, *Accounts of Chemical Research, 54*(4), 827-836.

Gallegos, M., Vassilev-Galindo, V., Poltavsky, I., Martín Pendás, Á., & Tkatchenko, A. (2024), Explainable chemical artificial intelligence from accurate machine learning of real-space chemical descriptors, *Nature Communications, 15*(1), 4345.

Gao, Y., Chen, N., Jiang, X., & Yang, X. (2024), Application of α-bromination reaction on acetophenone derivatives in experimental teaching: a chemical innovation experiment engaging junior undergraduates, *BMC chemistry, 18*(1), 38.

Ghanbari, S., Haghani, F., Barekatain, M., & Jamali, A. (2020), A systematized review of cognitive load theory in health sciences education and a perspective from cognitive neuroscience, *Journal of Education Health Promotion; 9*.

Greenaway, R. L., & Jelfs, K. E. (2021), Integrating computational and experimental workflows for accelerated organic materials discovery, *Advanced Materials, 33*(11), 2004831.

Gupte, T., Watts, F. M., Schmidt-McCormack, J. A., Zaimi, I., Gere, A. R., & Shultz, G. V. (2021), Students' meaningful learning experiences from participating in organic chemistry writing-to-learn activities, *Chemistry Education Research Practice; 22*(2), 396-414.

Jankowski, E., Ellyson, N., Fothergill, J. W., Henry, M. M., Leibowitz, M. H., Miller, E. D., Klopfenstein, M. (2020), Perspective on coarse-graining, cognitive load, and materials simulation, *Computational Materials Science, 171*, 109129.

Jordan, J., Wagner, J., Manthey, D. E., Wolff, M., Santen, S., Cico, S. J., & training. (2020), Optimizing lectures from a cognitive load perspective, *AEM education training; 4*(3), 306-312.

Jordan, R. B. (2024), Covalent Bonding Theories, In *Principles of Inorganic Chemistry: Basics and Applications;* (pp. 45-92): Springer.

Kazim, M., Wang, M., Vemulapalli, S., Nguyen, P. M., Wang, Y., Siegler, M. A., Lectka, T. (2023), How Do Face-to-Face Stacked Aromatic Rings Activate Each Other to Electrophilic Aromatic Substitution, *Organic Letters, 25*(23), 4318-4322.

Keller, S., Rumann, S., & Habig, S. (2021), Cognitive load implications for augmented reality supported chemistry learning, *Information, 12*(3), 96.

Kiliclar, H. C., Altinkok, C., Yilmaz, G., & Yagci, Y. (2021), Visible light induced step-growth polymerization by electrophilic aromatic substitution reactions, *Chemical Communications, 57*(44), 5398-5401.

Lespiau, F., & Tricot, A. (2024), Reasoning More Efficiently with Primary Knowledge Despite Extraneous Cognitive Load, *Evolutionary Psychology, 22*(2), 14747049241252694.

Li, J., Zhang, S., Lao, J., & Zou, H. (2021), Direct Transition-Metal Free Benzene C– H Functionalization by Intramolecular Non-Nitroarene Nucleophilic Aromatic Substitution of Hydrogen to Diverse AIEgens, *ChemSusChem, 14*(15), 3208-3218.

Li, S., Liu, W., & Xia, X.-F. (2023), Silver-catalyzed nitrosation and nitration of aromatic amides using NOBF 4, *Organic Biomolecular Chemistry; 21*(47), 9428-9432.

Maj, S. P. (2020), *Cognitive load optimization–a statistical evaluation for three STEM disciplines.* Paper presented at the 2020 IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE).

Martella, A. M., Lawson, A. P., & Robinson, D. H. (2024), How Scientific Is Cognitive Load Theory Research Compared to the Rest of Educational Psychology, *Education Sciences, 14*(8), 920.

Mikolajczyk, A., Zhdan, U., Antoniotti, S., Smolinski, A., Jagiello, K., Skurski, P., Polanski, J. (2023), Retrosynthesis from transforms to predictive sustainable chemistry and nanotechnology: a brief tutorial review, *Green Chemistry, 25*(8), 2971-2991.

Mikulak-Klucznik, B., Gołębiowska, P., Bayly, A. A., Popik, O., Klucznik, T., Szymkuć, S., Beker, W. (2020). Computational planning of the synthesis of complex natural products, *Nature, 588*(7836), 83-88.

Mistry, N., & Shahid, N. (2021), Design and delivery of virtual inquiry-based organic chemistry experiments, *Journal of chemical education, 98*(9), 2952-2958.

Mosiagin, I., Fernandes, A. J., Budinská, A., Hayriyan, L., Ylijoki, K. E., & Katayev, D. (2023), Catalytic ipso-Nitration of Organosilanes Enabled by Electrophilic N-Nitrosaccharin Reagent, *Angewandte Chemie, 135*(41), e202310851.

Nakatani, K., Teshigawara, S., Tanahashi, Y., Kasahara, K., Higashi, M., & Sato, H. (2022), Solvation in nitration of benzene and the valence electronic structure of the Wheland intermediate, *Physical Chemistry Chemical Physics, 24*(27), 16453-16461.

Nesterov, I., Belen'kii, L., & Pivina, T. (2021), Quantum chemical simulation for the mechanism of benzene bromination, *Russian Chemical Bulletin, 70*, 1080-1083.

Peeters, H., Habig, S., & Fechner, S. (2023), Does augmented reality help to understand chemical phenomena during hands-on experiments?–implications for cognitive load and learning, *Multimodal Technologies Interaction; 7*(2), 9.

Ping, R., Church, R., Decatur, M.-A., Larson, S. W., Zinchenko, E., & Goldin-Meadow, S. (2021), Unpacking the gestures of chemistry learners: What the hands tell us about correct and incorrect conceptions of stereochemistry, *Discourse processes; 58*(3), 213-232.

Qin, M., Qiu, S., Zhao, Y., Zhu, W., & Li, S. (2024), Graphic or short video? The influence mechanism of UGC types on consumers' purchase intention Take Xiaohongshu as an example, *Electronic Commerce Research Applications; 65*, 101402.

Quintero-Manes, R., & Vieira, C. (2024), Differentiated measurement of cognitive loads in computer programming, *Journal of Computing in Higher Education;* 1-18.

Ramírez, J. Á., & Bueno, A. M. V. (2020), *Learning organic chemistry with virtual reality.* Paper presented at the 2020 IEEE international conference on engineering veracruz (ICEV).

Sedlar, A. R., Roncevic, T. N., & Horvat, S. A. (2023), *The Application of Interactive Learning Tasks Made by Using Digital Hybrid Illustrations in the Topic" Hydrocarbons" in Eighth-Grade Organic Chemistry Classes*. Paper presented at the International Baltic Symposium on Science and Technology Education.

Sibomana, A., Karegeya, C., & Sentongo, J. (2020), Students' conceptual understanding of organic chemistry and classroom implications in the Rwandan perspectives: A literature review, *African Journal of Educational Studies in Mathematics Sciences; 16*(2), 13-32.

Sozio, G., Agostinho, S., Tindall-Ford, S., & Paas, F. (2024), Enhancing Teaching Strategies through Cognitive Load Theory: Process vs. Product Worked Examples, *Education Sciences, 14*(8).

Stamenković, N., Ulrih, N. P., & Cerkovnik, J. (2021), An analysis of electrophilic aromatic substitution: a "complex approach", *Physical Chemistry Chemical Physics; 23*(9), 5051-5068.

Sweller, J. (2020), Cognitive load theory and educational technology, *Educational technology research development; 68*(1), 1-16.

Sweller, J. (2023), Discussion of the special issue on cognitive load theory, *British Journal of Educational Psychology; 93*, 402-410.

Tatiya, G., Francis, J., Wu, H.-H., Bisk, Y., & Sinapov, J. (2023), Mosaic: Learning unified multi-sensory object property representations for robot perception, *arXiv preprint arXiv:.08508*;

Timothy, V., Fischer, F., Watzka, B., Girwidz, R., & Stadler, M. (2023), Applying cognitive load theory in teacher education: An experimental validation of the scale by Leppink, *Psychological Test Adaptation Development; 4*(1), 246.

Ueno, K., Nishii, Y., & Miura, M. (2021), Electrophilic substitution of asymmetrically distorted benzenes within triptycene derivatives, *Organic Letters; 23*(9), 3552-3556.

Urbano, R. D., & Caballes, D. G. Measuring Cognitive Load in Blended Laboratory Setting: Toward Enhanced Learning in Chemistry.

Voinarovska, V., Kabeshov, M., Dudenko, D., Genheden, S., & Tetko, I. V. (2023), When yield prediction does not yield prediction: an overview of the current challenges, *Journal of Chemical Information Modeling; 64*(1), 42-56.

Weinhold, F. (2003), Rebuttal to the Bickelhaupt-Baerends case for steric repulsion causing the staggered conformation of ethane, *Angewandte Chemie International Edition, 42*(35), 4188-4194.

Williams, N. D., Gallardo-Williams, M. T., Griffith, E. H., & Bretz, S. L. (2021), Investigating meaningful learning in virtual reality organic chemistry laboratories, *Journal of Chemical Education; 99*(2), 1100-1105.

Wu, Y., Lu, W., Ma, Y.-N., Chen, F., Ren, W., & Chen, X. (2023), Trifluoromethanesulfonic Acid Promoted Controllable Electrophilic Aromatic Nitration, *The Journal of Organic Chemistry, 88*(15), 11322-11327.

Yang, J., Wang, P., Neumann, H., Jackstell, R., & Beller, M. (2023), Industrially applied and relevant transformations of 1, 3-butadiene using homogeneous catalysts, *Industrial Chemistry Materials; 1*(2), 155-174.

Yu, X., Zhu, W., Liu, H., Liu, Y., Li, H., Han, J., Xia, C. (2022), Practical chemoselective aromatic substitution: the synthesis of N-(4-halo-2-nitrophenyl) benzenesulfonamide through the efficient nitration and halogenation of N-phenylbenzenesulfonamide, *Organic Biomolecular Chemistry; 20*(27), 5444-5451.

Zhao, Y. (2023), The Impact of Cognitive Load Theory on Online Learning Outcomes for Adolescent Students, *Journal of Education, Humanities Social Sciences; 18*, 50-55.

Zotos, E. K., Tyo, J. J., & Shultz, G. V. (2021), University instructors' knowledge for teaching organic chemistry mechanisms, *Chemistry Education Research Practice; 22*(3), 715-732.