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Introduce-Operate-Network (ION) Model: A Teaching Innovation on Formula Writing and Naming of Compounds in Chemistry

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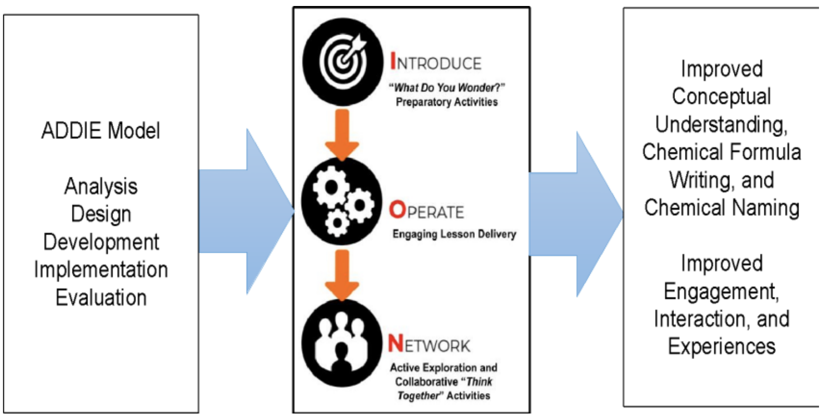
Chemistry education poses significant challenges, particularly in grasping fundamental concepts like formula writing and compound nomenclature. The complexities involved, such as confusion between valency and oxidation numbers, underscore the need for innovative teaching approaches. To address this, the researchers designed, developed, implemented, and evaluated an Introduce-Operate-Network (ION) learning model, integrating visual, interactive, and collaborative elements. The expert assessment confirmed the model's content validity, with a highly acceptable score of 4.93. Reliability testing demonstrated its effectiveness in assessing student performance, with Cronbach's alpha values of 0.890 for concept tests and 0.726 for student feedback surveys. Implementation with sixty Grade 12 students revealed substantial gains, with the experimental group outperforming the control group significantly. The experimental group achieved a mean increase of 8.90, compared to 0.37 for the control group. Statistical analysis confirmed these findings, with significant improvement within each group (control group: $t(29)$=0.52, p=.602; experimental group: t(29)=11.80, p=.000) and a significant difference in mean gains between groups ($t(58)$=8.32, p=.000) with a strong effect size (Cohen's d=2.15). Thematic analysis of student experiences highlighted the efficacy of the ION learning model in facilitating step-by-step learning, though challenges were noted. The ION learning model emerged as a powerful tool for enhancing student understanding of formula writing and compound naming. Future research endeavors should focus on refining the model and exploring its broader applicability in science education.

Graphical abstract



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1. Introduction

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A good and robust foundational knowledge of chemistry is highly relevant and beneficial when learning about other subjects [1]. For example, in understanding molecular structures, Chemistry provides the foundational knowledge needed to understand the structures of biomolecules, such as proteins, nucleic acids, lipids, and carbohydrates. These structures are crucial for comprehending the functions of biological molecules. Teaching Chemistry and other science disciplines poses challenges and issues that must be addressed to attain high academic achievement among students in science classes [2]. Analyzing the state of science education in the nation can offer insights into effectively addressing these challenges.

The study of Bernardo et al. [3] examines how Filipino students view their science classes to investigate whether certain teaching-related factors are linked to a decline in science achievement from elementary to high school and contribute to gender differences in science achievement. As a result, it is noteworthy that there is a decline in perceived inquiry-oriented activities, suggesting that science teachers in higher grades may not be pushing their students to engage in the more complex modes of thinking appropriate for learning science. There can be numerous factors that prevent the teachers from fulfilling this expectation. Tijap et al. [4] conducted survey research involving 464 Filipino Science teachers to determine their needs, challenges, and practices in teaching Science. The compiled data indicated that teachers required additional training and updating in content-related knowledge and effective teaching strategies for specific challenging science topics in the current educational environment, ongoing instruction on utilizing diverse online platforms, and enhanced skills in employing software and digital applications for science activities.

The need for teachers to train and update their content knowledge on lessons may relate to the reason why they need students to engage in high-level thinking in the activities that they do in the classroom. Insufficient teacher training in pedagogical knowledge can be a significant obstacle in designing practical lessons. The students may need to be equipped with the necessary foundational knowledge in Chemistry for further education and daily life [5]. Due to this, many Filipino Chemistry education researchers conduct studies to assist teachers in improving students' knowledge and skills, as evident in innovative strategies such as multiple representations [6-9], at-home experiments [10-11], contextualized instructional materials [12], digital materials [13], videos [14], and online tools [15].

In the study of Deleña and Marasigan [16], it was revealed that students have challenges when writing chemical formulas. They often misunderstand the ionic compound's chemical formula, incorrectly representing them as charged species. Additionally, there is a lack of understanding about valency and the cross-charge method. It was also found that students make mistakes in representing radicals, and when naming ionic compounds, students commonly make errors. They misname elements in binary ionic compounds and incorrectly name metal ions with more than one charge and polyatomic ions. Shana and Abulibdeh [17] advised that secondary school students should be given sufficient chances to participate in hands-on lessons that ensure that schools equip the science classes with all necessary materials to implement practical activities successfully. Sanchez [6-8], Opona et al. [9], and Kapici [18] recommended emphasizing the representation levels in chemistry during instruction. The use of visual representations can assist students in applying the rules and conventions of formula writing and naming.

Chemical formulas are the vocabulary words in Chemistry; it is necessary to start with the fundamental concepts, then be followed by hands-on activities, demonstrations, or visual aids to help students understand abstract concepts and to always emphasize the importance of practice and repetition in reinforcing learning, using numerous drills and practice exercises [19]. A hands-on learning approach has increased student engagement and understanding of scientific concepts [20]. Furthermore, teaching strategies that elicit and engage students' prior ideas must come before instruction [21]. The students' thinking has to be activated by connecting the lesson to certain phenomena in their lives.

The American Chemical Society (ACS), one of the world's largest scientific organizations, highlighted several teaching strategies for high school chemistry. It is suggested that teachers need to plan lessons and establish clear learning goals. Providing choices to students in the chemistry classroom enriches their understanding of the content. It can help increase student motivation when students are active participants in their learning and are given the chance to present their perspectives [22].

This study developed, implemented, and evaluated an instructional model that could help teachers effectively teach the topic of chemical formula writing and nomenclature or the naming of ionic and covalent compounds. The instructional model was developed based on the ADDIE model. The needs assessment and literature review results were considered and incorporated in creating well-designed lessons aligned with the standards depicted in the K to 12 Basic Education Curriculum [23]. The outline of the topics in the learning plans follows the sequence of the curriculum guide, which is progressively built. The students learn about representing ionic and covalent compounds using chemical formulas, structural formulas, and models and then name compounds given their formulas. With this, chemistry teachers can deliver highly effective lessons by following a learning model that promotes student comprehension, engagement, and interaction in their classes.

Statement of the Problem

To achieve the purpose of this study, the following research questions were addressed: (1) What are the strategies for teaching formula writing and naming ionic compounds based on (a) a literature review and (b) the experiences of students and teachers? (2) What strategy or learning model can be crafted based on the literature review and experiences of students and teachers? (3) How is the proposed strategy implemented in the science classroom? (4) What is the student's performance before and after implementing the proposed learning model? (5) Is there a significant mean gain between the pre-post-test performance of the control and experimental groups? (6) Is there a significant difference in the mean gain between the control and experimental groups? (7) What is the level of acceptability among the students in terms of (a) engagement, (b) comprehension, and (c) interaction? (8) What are students' experiences implementing the proposed learning model?

2. Material and Methods

This study utilized research and development design (R&D) using the ADDIE model. The ADDIE model is an instructional design tool that can help professionals create, organize, and streamline effective learning and development programs. Although developed in the 1970s, it remains the most commonly used model for instructional design because it is simple yet highly effective [24]. The ADDIE model in education encompasses five essential phases: Analysis, Design, Development, Implementation, and Evaluation. These phases provide a structured framework for instructional design, ensuring effective learning outcomes [24].

Analysis Phase

This study's analysis phase is crucial, as it examines raw data and is refined into actionable insights, laying the groundwork for effective instructional design. The researchers undertook a scoping literature review, employing the inclusion and exclusion criteria presented in Table 1, to uncover the underlying dynamics of the various strategies in teaching formula writing and naming of ionic compounds in various classroom learning environments on a global scale.

Table 1. Inclusion and exclusion criteria for the literature review

Criteria	Inclusion	Exclusion
Publication Year	Published from 2004-2024	Published before 2004
Language	Published in English	Published in a language other than English
Document Type	Journal articles, online magazine/newspaper articles, conference paper and proceedings	Other document types
Type of Research Participant	Basic and higher education students	Graduate school students
Focus	Teaching strategies in teaching Chemistry specifically on chemical formula writing and naming of compounds	Teaching strategies not related to Chemistry and chemical formula writing and naming of compounds

Moreover, the elucidated findings derived from a comprehensive analysis conducted to understand the intricacies of teaching formula writing and naming ionic compounds will aid the researchers in devising a learning model. Through a rigorous exploration of data, feedback, and observations, the researchers aimed to discern patterns, challenges, and opportunities that shape the instructional objectives of the study.

Furthermore, the researchers conducted a semi-structured interviews with Grade 12 STEM students who had completed their General Chemistry 1 course and teachers responsible for teaching this subject in a private school in Cebu City in Central Visayas, Philippines. These interviews were foundational in understanding the target audience's specific learning needs, challenges, and preferences. By engaging directly with students, the researchers aimed to gain insights into the students' prior knowledge, conceptual understanding, and perceived difficulties related to formula writing and naming of ionic compounds. Additionally, semi-structured interview with teachers provided valuable perspectives on instructional practices, curriculum requirements, and areas for improvement within the existing teaching framework. Through these interviews, the researchers sought to gather rich qualitative data that informed the learning model's subsequent design and development phases.

Design and Development Phases

In the design phase, the researchers meticulously crafted learning objectives tailored to address the identified needs and goals of the students based on the insights from the literature review and participants' semi-structured interviews in the analysis phase. By synthesizing findings from these two sources, the researchers ascertained critical areas of focus and proficiency desired by the selected participants in the formula writing and naming of ionic compounds. These learning objectives guided the selection of appropriate instructional strategies and designing engaging learning activities and materials. Researchers integrated multimedia resources and interactive exercises to enhance student engagement and comprehension, considering diverse learning styles and abilities to ensure inclusivity and effectiveness.

Building upon this design, the researchers constructed a comprehensive learning model during the development phase, synthesizing critical insights from the preceding analysis and design phases. They intricately wove together essential components of the learning model, meticulously creating instructional materials, activities, and assessments tailored to support student engagement, facilitate knowledge acquisition, and foster skill development. By ensuring that the instructional materials and activities aligned with the learning objectives and incorporating the planned interactive and multimedia elements, the researchers aimed to create an inclusive and practical learning experience using various instruments. These instruments encompassed the development of semi-detailed lesson plans tailored to the specific needs and objectives. These two-week learning plans served as structured frameworks guiding the delivery of instructional content and activities designed to enhance student comprehension and mastery of formula writing and naming of ionic compounds.

Furthermore, this study utilized a researcher-made concept test for pretest and post-test assessments as an integral research instrument. The researchers meticulously designed this 30-item concept test to evaluate the student's understanding of critical concepts related to formula writing and naming ionic compounds before and after the instructional intervention. It consisted of three parts, namely, 10-item conceptual understanding, 10-item chemical formula writing, and chemical naming. To measure the level of acceptability in terms of engagement, comprehension, and interaction among participants in the experimental group, the researchers also utilized a survey questionnaire with a four-point Likert scale containing five statements for each sub-variable. Also, this study used semi-structured interview guide questions created by the researchers to solicit feedback and experiences among the experimental group concerning the implemented learning model. Lastly, the aforementioned research instruments were subjected to a reliability test, and the results indicated that the tools are reliable to be used in the study context [25], as presented in Table 2.

Table 2. Reliability test results of the tools

Tool	Cronbach's alpha	Interpretation
Pretest/Posttest	0.890	Good
Acceptability	0.726	Acceptable

Legend: Unacceptable (<0.5), Poor (0.51-0.60), Questionable (0.61-0.70), Acceptable (0.71-0.80), Good (0.81-0.90), Excellent (>0.90)

Implementation Phase

In this phase, the researchers submitted and sought the approval of the transmittal letter to the school principal, formally requesting authorization for the researchers to deploy and implement the crafted learning model in a real-world educational science classroom setting at the said private school, targeting Grade 12 Prebaccam laureate Maritime Strand students who were currently taking the General Chemistry 1 course. The participants in this study consisted of 60 students selected using a purposive sampling method. This sample size was deemed sufficient to provide general evidence for the study's objectives. The purposive sampling method allowed for the selection of participants who were particularly relevant to the research questions, ensuring that the data collected was rich and informative. While larger sample sizes can enhance the statistical power and generalizability of findings, the depth and specificity of insights gained from this focused group effectively support the study's conclusions in this context. These students were divided into two groups: an experimental group of 30 students and a control group of 30 students. The experimental group received a customized teaching approach based on the proposed learning model, supplemented by specially designed instructional materials tailored to enhance their learning experience. In contrast, the control group underwent traditional lecture-based instruction. Before delivering the instruction for both groups, the researchers conducted a content validation of the ION learning model and concept test through the four experts in the field using a standardized tool developed by Sanchez [26]. After integrating experts' feedback, the researchers administered a pre-test utilizing the validated researcher-made concept test on both groups' formula writing and naming of ionic compounds. The pre-test served as a baseline assessment to gauge the students' initial understanding of the subject matter before implementing the newly developed teaching strategy. Subsequently, the designated teacher implemented the subject matter according to the validated lesson plan, incorporating the newly developed teaching strategy and instructional materials. At the same time, the researchers monitored student progress, provided feedback, and adjusted the instructional approach as needed to optimize learning outcomes.

Evaluation Phase

In the last phase of the ADDIE model, researchers assessed the effectiveness of the proposed learning model in achieving its intended learning objectives and outcomes. This involved collecting and analyzing quantitative data on student achievement by administering a post-test to measure knowledge gains, a survey questionnaire to evaluate the level of acceptability among students regarding engagement, comprehension, and interaction, and qualitative data through soliciting feedback from students and their experiences via focused group discussion. Post-test items were interchanged compared to those used in the pre-test, ensuring a fair and unbiased evaluation of student learning outcomes. The findings from the evaluation phase informed iterative improvements to the learning model, ensuring ongoing refinement and enhancement of instructional effectiveness.

Subsequently, researchers employed several statistical techniques to analyze and interpret the study's data effectively. Mean scores and standard deviations were utilized to determine the degree of dispersion and characterize the distribution of both pretest and posttest scores. Additionally, to assess the mean gain from pre-test to post-test scores and ascertain if implementing the tailored teaching strategy and instructional materials resulted in a significant difference in student understanding, a t-test for one sample was conducted at a confidence level with a p-value of 0.05. To compare the mean gains between the pre-test and post-test performance of the control and experimental groups, a t-test for independent samples was employed, also set at a 95% confidence level with a p-value of 0.05. Finally, to explore the students' learning experiences with the tailored teaching strategy and instructional materials, a thematic analysis following the framework proposed by Braun and Clark [27] was conducted. This analysis entailed six phases, including becoming familiar with the data, generating initial codes, searching for themes, reviewing the themes, defining the themes, and ultimately, writing up the findings.

3. Results and Discussion

Analysis of the Scoping Literature Review

In developing an innovative learning model for teaching formula writing and naming of chemical compounds in Chemistry using the ADDIE framework, the initial phase, Analysis, requires a thorough examination of relevant literature. This analysis helps identify effective strategies and insights that inform the design of a robust and engaging educational model. The results of the scoping literature review characterized the various strategies in teaching formula writing and naming of compounds in Chemistry, as reflected in Table 3.

Table 3 revealed the characteristics of effective strategies in teaching formula writing and the names of compounds in Chemistry. Many strategies have been found to draw in students and establish a solid basis for the lesson. Schmidt [31] highlighted the significance of using pictures, movies, and demonstrations to develop a connection between macroscopic representations and the molecular level. Students can learn the content more effectively if abstract notions are made more concrete. This lesson's foundation is laid firmly with the help of this visual and contextual introduction.

The heart of the lesson reveals that experiential and hands-on learning methodologies work very well. Logerwell et al. [28] advocate for game-based learning, in which students actively interact with essential ideas concerning synthesizing ionic compounds. Students can learn about various ionic compounds using this interactive approach, reinforcing their comprehension through repeated engagement. According to Wu and Shah [30], visual-spatial thinking is essential for improving understanding and lowering errors in Chemistry. Students can understand complicated topics far more quickly when explicit information is provided along with precise visual representations.

Additionally, collaborative learning is a valuable strategy. Mulvey [29] talks about the advantages of pattern recognition in cooperative learning settings when students help each other learn. This cooperative method fosters community in the classroom and reinforces comprehension. Another essential component is clearing up misconceptions and ensuring knowledge is retained. Chew [32] highlights the significance of permanently establishing knowledge through practice. This entails giving students many opportunities to apply concepts and abilities, formative tests, and prompt feedback. Lukman Abdul et al. [33] emphasize the significance of students creating scientific explanations to communicate and elucidate their comprehension of scientific events. This exercise improves reasoning and critical thinking abilities while offering insightful feedback for judgments made in the classroom.

Table 3. Characterization of strategies in teaching formula writing and naming of compounds

Strategy Employed	Nature of the Strategy	Type
Hands-on Game-Based Learning [28]	Students actively engage students in processing key concepts related to ionic compound formation and ionic formula writing. Further, the fact that different compounds can be made each time students play helps them realize that there are thousands of unique ionic compounds. During the activity, students play on teams and are equally responsible for the compounds formed.	Experiential Learning
Pattern Identification [29]	Pattern identification within cooperative learning groups encourages students to support each other in their learning.	Collaborative Learning
Visuospatial thinking [30]	The visualization of chemical representation that connects to the conceptual component of the lesson is very important as it helps in reducing errors and overcoming difficulties in Chemistry. It is added that one of the ways to do this is to present descriptions and state information explicitly.	Use of Visuals, Emphasizing Important Vocabulary Words
Connecting Macroscopic Representation to the Molecular Level [31]	One of the effective ways to strengthen and deepen students' learning in Chemistry is to give opportunities to make the subject visible and to be intentional in designing lessons that will allow students to experience the macroscopic level and connect it to the molecular level. Additionally, using demonstrations and illustrations can help molecular-level concepts visible thereby making it easier to understand.	Use of Illustrations, Videos, and Demonstrations
Making Knowledge Permanent through Practice [32]	One of the teaching techniques that is effective in correcting misconceptions is repeatedly pointing out and addressing these incorrect conceptions and debunking them. When students show their work, giving immediate feedback and processing their thinking can help students correct their mistakes. Giving formative assessments can also improve learning when students are guided on how to think through the questions and give them many opportunities to practice applying the concepts and skills taught to them. For long-term learning to take place where students can retain important information beyond the test, they have to think about the information given to them meaningfully by making connections with their previous knowledge or relating it to other concepts.	Giving of Formative Assessments through practice/drills, reviewing previous knowledge
Constructing Scientific Explanation [33]	Students need to communicate and explain scientifically the scientific phenomena and tasks as this is a significant part of chemistry subject in high school. The way students communicate their learning individually and collectively can give feedback on their understanding of the lesson and can inform instructional decisions.	Engagement with Chemistry concepts by developing critical thinking and reasoning skills
Interdependent Cooperative Learning [34]	Encouraging interdependence among students, where they rely on each other to achieve common goals, increases their collaborative engagement and enhances their classroom experience.	Collaborative Classrooms
Simulated Chemistry Practicals [35]	When students are allowed to interact with simulations, it can deepen their understanding of scientifically correct concepts. It can motivate them to tackle challenges and problem-solving tasks that are technology-based.	Simulations, Online Games
Computer Simulations in Science Instruction [36]	When used as supplements that encourage student reflection, computer-simulated science activities can be more effective as an instructional practice in promoting science content learning, enhancing processing skills, and improving conceptual foundational knowledge.	Simulations, Online Games

The last section of the analysis gives students the chance to participate in technology-based, collaborative learning experiences. Premo et al. [34] emphasize the advantages of interdependent cooperative learning, where students depend on one another to accomplish shared objectives. This method improves group participation and enriches the learning environment. Jabeen and Afzal [36] highlight how interactive, scientifically realistic chemistry simulations give students a deeper understanding of the subject and inspire them to take on new challenges. Similarly, Smetana and Bell [36] endorse using computer simulations as add-ons that foster learning objectives, improve conceptual understanding, foster student reflection, and strengthen processing abilities.

Analysis of the Interviews

Aside from the scoping review, semi-structured interviews were conducted during the analysis phase. The learning needs, challenges, and preferences of the students and teachers in learning and teaching formula writing and naming of ionic compounds were assessed through interviews with the teachers and students who had already taken up the course. After thoroughly and rigorously examining the data, researchers delved into the categories, themes, and findings extracted from the initial dataset. They honed in on a central concept, streamlining the information by eliminating redundancies. This meticulous process yielded three (3) essential themes, as shown in Table 4 below.

Visual and hands-on learning experiences greatly aid students' understanding of formula writing and ionic compound naming. Student I9 said, *"I use acronyms to memorize and classify the terms, but my main strategy has always been knowing the etymology of the word, why it is named the way that it is, sometimes its history or any detail in its name that I could relate to its characteristic to have an in-depth understanding and therefore be able to recall it easily."* Diagrams and molecular models help students visualize abstract concepts through visual learning [37]. Through practical experiments and demonstrations, experiential learning fosters a more profound comprehension of concepts and strengthens theoretical knowledge [14,38]. These methods encourage active participation and accommodate various learning preferences, eventually improving chemistry education's learning objectives. Students' feedback emphasizes multiple techniques, including practice problems, mnemonic devices, and visual aids, for comprehending and recalling chemical topics.

Table 4. List of themes, subthemes, and code frequencies derived from interview analysis

Themes	Subthemes	Code Frequency
Introductory Activities	1. Visual and experiential learning	4
	2. Incorporation of videos and visuals	6
Operational Tasks	1. Interactive and engaging lessons	5
	2. Repetition and review	2
	3. Formative assessment	3
Networking Opportunities	1. Participatory activities	7
	2. Collaborative learning	3

Theme 1: Introductory Activities. The value of experiential and visual learning methods in chemistry education is increasingly acknowledged. Multimedia materials, especially movies and images, are being used by teachers more and more as effective methods to improve learning. This emphasis on experiential and visual learning aims to establish dynamic and stimulating learning environments.

Integrating educational videos and visual aids provides engaging information to enhance conventional teaching approaches. Student I7 shared, *"Making mnemonics and practicing your notes are the most profound ways of understanding and remembering inorganic compound nomenclature. Making your rhythm or easily tuned songs is also one of the most effective ways."* Videos provide a multimodal learning experience by appealing to the senses of hearing and sight [14,39]. The integration of music elements in the lesson may trigger associations making it easier to remember facts and concepts. Infographics and diagrams are visual aids that can make abstract concepts more relatable [40]. Step-by-step assistance is provided by instructional videos that illustrate formula writing and naming norms; this improves understanding and memory [14,41]. To help students comprehend and recall chemical vocabulary, they also stress the value of mnemonic devices, note-taking, active listening, and flashcards.

Theme 2: Operational Tasks. Operational duties in instructional design center on dynamic, captivating teachings that actively engage students in the ever-changing world of education. This strategy seeks to maximize student engagement, comprehension, and retention through active student participation in their education.

Effective learning results in formula writing and ionic compound naming depend on dynamic and captivating lessons [42]. These classes include interactive exercises and demonstrations that let students work with chemicals and watch reactions to encourage student participation, leading to a more robust comprehension and appreciation of chemical concepts. Students actively interact with the content with note-taking, quizzes, and mnemonic devices. For instance, Student I1 highlighted the blurting method, *"The process includes reading the given information, and afterward, I will get a piece of paper and list all the knowledge I obtained. Repeating the process until I get all the important information."* By encouraging students to develop their understanding actively, this proactive approach produces learning outcomes that are more meaningful and long-lasting [43].

Repetition and review are essential to improve understanding and recall of challenging chemical ideas. Students can absorb and eventually become experts in concepts when they are exposed to them repeatedly [44]. Student I8 pointed out, *"It is also good to be repeatedly exposed to the topic, maybe short quizzes or games that can help students recall, engage with the class, and have fun."* Students are aware of the benefits of this method. *"Teachers should teach the nomenclature of inorganic compounds by giving a thorough explanation of what it is and why it is named like that,"* highlighted Student I4, emphasizing comprehensive explanations and ongoing evaluation. These realizations underline the value of practice and review in strengthening comprehension and encouraging participation.

Formative assessment is essential for determining student retention and comprehension since it involves frequent quizzes and drills [45]. Student I3 suggested, *"Teachers should give out more quizzes, answer sheets, or activities...making drills can also be a way"*, indicating that students respect these assessments. Student I6 supported this, *"Ungraded drills can help the students familiarize with the terms, especially drills with twists are fun for the students,"* highlighting the enjoyable element of the exercises. Through fun and interactive exercises, these tests encourage active participation and assist students in learning chemical principles.

Theme 3: Networking Opportunities. For chemistry education to be effective, student participation in formula writing and compound naming is essential. Studies indicate that cooperative learning, group projects, and technological integration can significantly augment students' self-assurance and competence in these domains [46-48]. Collaborative learning and participatory activities are the two subthemes that are highlighted here.

It is crucial to participate actively through thought-provoking conversations and activities. They highly value opportunities for students to participate in group projects and interactive exercises in the classroom. Repetition and exposure are essential, as Student I2 pointed out, *"Provide many examples and review the lesson every time until the students can."* According to Student I9, *"It is also good to be repeatedly exposed to the topic, maybe short quizzes or games that can help students recall, engage with the class, and have fun."* Interactive activities play a significant role in developing engagement and retention [49-50]. These viewpoints emphasize how crucial involvement is in promoting a greater comprehension of chemical principles.

Teaching formula writing and ionic compound naming requires student collaboration and shared learning opportunities. Cooperative exercises, peer tutoring, and group projects encourage student engagement and comprehension [46-48,51]. As an illustration of the importance of teamwork in enhancing learning outcomes, Student I7 suggested, *"Collaborative make more a Q & A portion to be able the students to experience answering naming inorganic compound."* Student I5 opined, *"They could also add videos or visuals to make it more engaging for groups of students and also to make it more comprehensible."* These observations highlight how cooperative learning fosters inclusive, dynamic settings that aid students in grasping challenging chemical ideas.

Design and Development of the Learning Model

Based on the analysis phase, teaching formula writing and naming of ionic compounds should incorporate a thorough strategy that meets various learning demands. Essential techniques for reinforcing learning include drills, quizzes, repetition, and review. Including interactive tests and reviews, sessions give students many chances to solidify their knowledge. Multimedia tools and educational movies are visual aids that support various learning styles and improve comprehension. Furthermore, experiential learning, group projects, and demonstrations encourage involvement and understanding. Utilizing technology to enhance engagement even more is possible with game-based learning and virtual simulations. Prioritizing student achievement in chemistry education, teachers can build dynamic environments that enhance mastery of formula writing and naming ionic compounds by implementing these creative, student-centered tactics.

Employing all the valuable information on teaching strategies that effectively bridge the abstract level and what is tangible to attain excellent student performance and considering all the characteristics of teaching strategies in formula writing and compound naming, a teaching model that follows the following steps can be implemented. This resulted in the proposed ION Learning Model, highlighted in Figure 1.

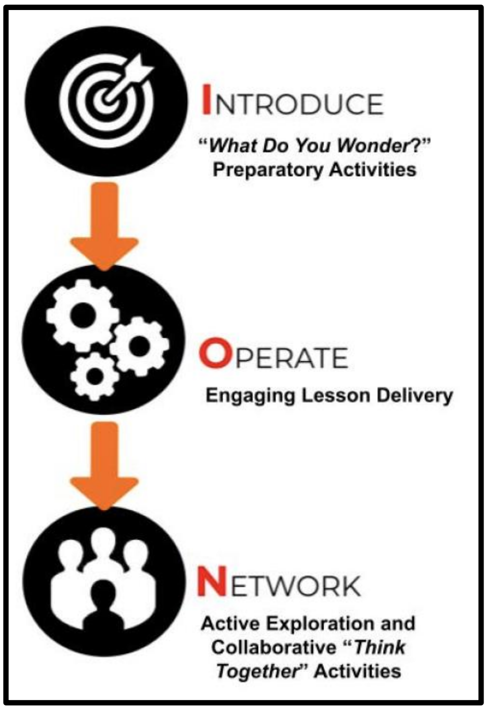


Fig. 1. The Introduce-Operate-Network (ION) Learning Model.

The ION learning model is a sequence of steps that serves as an instructional framework based on the needs analysis of students and teachers and the literature review. It is designed to guide and help chemistry teachers in planning, delivering, and assessing practical lessons on chemical formula writing and compound nomenclature. Each letter in the sequence represents a phase in the teaching and learning process, ensuring that classroom instruction is thorough, engaging, and tailored to meet the identified needs of students.

(I) Introduce: In the first phase of the lesson, the focus is on introducing the topic and setting the stage for learning, including preparatory activities, learning objectives, assessing prior knowledge, introducing vocabulary, and engaging students with hook activities to draw them into the lesson. Starting new lessons with students' ideas and experiences is highlighted as significant for initiating communication and connecting the lesson to real-life scenarios.

(O) Operate: The phase focuses on delivering chemistry learning content to students in a clear, organized, and engaging way. Teachers use various instructional strategies and techniques to convey information, such as direct instruction, visual aids, video simulations, interactive discussions, demonstrations, and models. The lesson context should be relatable and relevant, and students should be actively involved. Formative assessments are instituted to measure students' learning and mastery of lesson objectives. Different assessment tools measure student performance, identify growth areas, and inform instructional decision-making. The assessments demonstrate students' competency and readiness for graded assessments and future learning or application.

(N) Network. This phase emphasizes active student exploration and interaction with lesson content through group work. It allows students to apply knowledge and skills collectively, encourages active participation and collaboration, and reinforces newly acquired knowledge through guided practice activities and simulations. Students also have opportunities to work independently and with their peers to help reach learning goals.

Four content experts performed expert validation to ensure the learning design adequately covers the elements integrated into the learning model. Quantitative validation used a five-point-scale validation tool consisting of five domains: pedagogical approach, content relevance, technology integration, assessment strategies, and professional development, as shown in Table 5.

Table 5. Results of the expert validation of the ION learning model

Domain	Expert 1	Expert 2	Expert 3	Expert 4	Average
Pedagogical Approach	5.00	4.60	4.80	5.00	4.85
Content Relevance	5.00	4.80	4.80	4.80	4.85
Technology Integration	5.00	5.00	5.00	5.00	5.00
Assessment Strategies	5.00	5.00	5.00	4.80	4.95
Professional Development	5.00	5.00	5.00	5.00	5.00
Average	5.00	4.88	4.92	4.92	4.93
Description	Highly Evident	Highly Evident	Highly Evident	Highly Evident	Highly Evident

Legend: Highly Evident (4.2-5); Evident (3.4-4.19); Neutral (2.6-3.30); Less Evident (1.8-2.59); Not evident (1.0-1.79)

The ION learning model's expert validation outcomes in Table 5 show how well-liked and successful the instructional framework is in various fields. Pedagogical approach, content relevance, technology integration, assessment strategies, and professional development were all consistently regarded as very evident by experts. This suggests that the paradigm successfully promotes student involvement, guarantees the relevance of the content to their learning, and utilizes digital tools and resources. The experts also said that the model's method of assessing student learning was helpful for the development and application of teachers, and they strongly supported it. Due to the model's expert validity, the ION learning model was implemented to teach compound naming and drafting chemical formulas.

Implementation of the ION learning model

After the validation and refinement of the ION learning design, it was implemented within a two-week time frame. As presented in Figure 2, the learning plan was divided into three lessons.

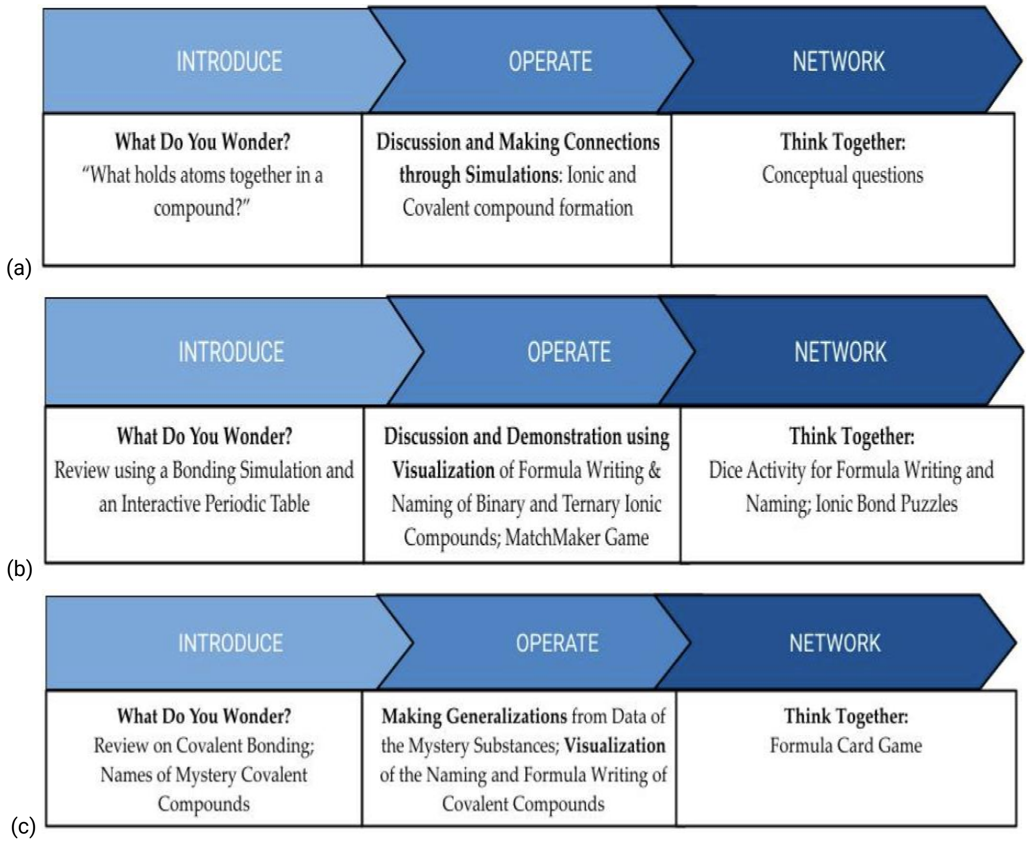


Fig. 2. Flow diagram of the ION learning model in the three lessons.

The first lesson was on the formation of ionic and covalent compounds. The lesson started with an introduction asking the students, "What holds atoms together in a compound?" The responses were anchored by cartoon images of atoms interacting in a compound. In the operating part, the first example discusses the formation of ionic and covalent compounds with NaCl compound. A tabular format was used to illustrate the formation. The discussion was related to the image used in the lesson introduction. For the network part, students worked in groups to answer the conceptual questions that checked their conceptual understanding of the lesson delivered.

The second lesson was on formula writing and naming binary and ternary ionic compounds. A review was done in the introduction, and the teacher showed the students an interactive periodic table. The students gave out pairs of elements and identified the type of compound formed. After the review, a discussion on determining the oxidation numbers of representative elements in the periodic table followed. Using the same elements from the review, Al and O, their oxidation numbers were identified based on their group numbers in the periodic table. A detailed discussion of the crisscrossing method took place using clear examples. After the formula was written, the rules for naming binary and ternary ionic compounds were tackled using varied examples. An independent worksheet was assigned for the students to answer as a formative assessment. It was followed by doing Levels 1-3 of the Matchmaker Game, an online game that offered multiple difficulty levels on the formula writing and naming of ionic compounds. On the network part, students worked in groups. The goal was to combine the two dice (one with various cations and another with multiple anions) to create an ionic compound, which could be a virtual dice. Students wrote the formula for the ionic compound and the corresponding name in the worksheet. The second part of this was solving ionic bond puzzles as a group.

The third lesson was on formula writing and naming of covalent compounds. The lesson began with an introduction by briefly reviewing the concept of covalent bonding and how the atoms share their electrons to form molecules. The students participated in a fun challenge to decipher the chemical formulas and names of mystery covalent compounds. For the operation part, all the correct chemical formulas and names of all the covalent compounds in the cards were given, and the students were asked to come up with the rules for naming covalent compounds. Students explained using the cards they paired up, and a thorough discussion of the lesson followed this. In the network part, students worked in groups to perform the Formula Card Game, in which they created chemical formulas for molecules/covalent compounds given chemical names.

Students' Performances

In determining the effectiveness of the ION learning model, the entry and exit performances of the control and experimental groups need to be calculated using the average mean and the t-test results, comparing them with the hypothetical mean, which is 60% standard. Three aspects of the calculation are the conceptual understanding of types of compounds, chemical formula writing, and chemical naming. Table 6 shows these results.

Table 6. Entry and exit performances of the students

Group	Aspect	Entry		Exit	
		Mean (SD)	t (p)	Mean (SD)	t (p)
Control	Conceptual Understanding	6.30 (1.47)	1.12^{ns} (.271) Average	7.20 (1,16)	5.69* (.000) Above Average
	Chemical Formula Writing	3.80 (1.79)	-6.74* (.000) Below Average	4.77 (2.56)	-2.64* (.013) Below Average
	Chemical Naming	5.00 (1.98)	-2.76* (.010) Below Average	3.50 (1.38)	-9.90* (.000) Below Average
	Overall	15.10 (2.58)	-6.15* (.000) Below Average	15.47 (3.36)	-4.13 (.000) Below Average
Experimental	Conceptual Understanding	6.53 (1.50)	1.94^{ns} (.062) Average	8.70 (0.84)	17.68* (.000) Above Average
	Chemical Formula Writing	6.07 (2.52)	0.15^{ns} (.889) Average	9.50 (0.63)	30.44* (.000) Above Average
	Chemical Naming	5.20 (1.96)	-2.24* (.033) Below Average	8.50 (1.23)	11.18* (.000) Above Average
	Overall	17.80 (4.27)	-0.26^{ns} (.799) Average	26.70 (1.32)	36.18* (.000) Above Average

Based on the hypothetical mean of 6 (for each aspect) and 18 (for the overall performance): Below Average (t<0, p<.05), Average (p>.05), Above Average (t>0, p<.05)

In Table 6, the experimental group outperformed the control group in both areas. Both groups performed below average in many aspects at first. Nevertheless, the experimental group outperformed the rest in terms of conceptual comprehension, writing chemical formulas, and chemical naming, as evidenced by their above-average exit ratings. This improvement shows that the experimental group's instructional strategies successfully improved student learning. Conversely, the control group only slightly improved, with several aspects still needing to catch up to the average. These outcomes highlight how well the new teaching strategy worked in the experimental group to improve students' general chemistry performance. The experimental group's performance improvement before and after the ION instructional intervention shows that strategically developed instructional materials can enhance students' performance even with varying learning abilities [13,52]. The model strengthened the learning of the topics because the students had opportunities to connect the macroscopic level with the molecular level through the varied strategies and tools employed [6-9,31].

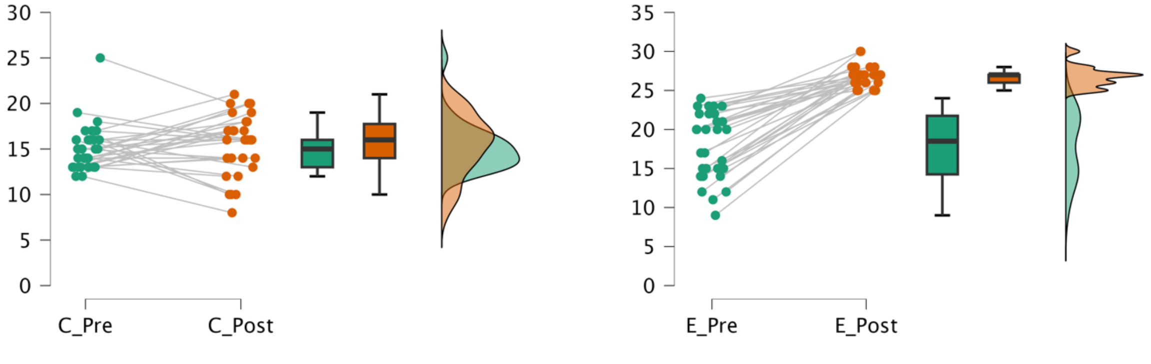
Comparing the entry and exit performances of the control and experimental groups gives a concrete description of how the ION learning design affects these groups' performance. Table 7 shows the overall calculation results of the mean gain, t-test, and Cohen's d, which indicate the standardized difference between the two means of the entry and exit levels.

Table 7. Comparative analysis between the entry and exit performances of the students

Group	Aspect	Mean Gain	t (p)	Cohen's d
Control	Conceptual Understanding	0.90	2.96* (.006)	0.54 Moderate
	Chemical Formula Writing	0.97	1.88^{ns} (.070)	0.34 Modest
	Chemical Naming	-1.50	-3.18* (.003)	-0.58 Moderate
	Overall	0.37	0,52 (.602)	0.10 Weak
Experimental	Conceptual Understanding	2.17	6.32* (.000)	1.15 Strong
	Chemical Formula Writing	3.43	6.87* (.000)	1.25 Strong
	Chemical Naming	3.30	11.29* (.000)	2.06 Strong
	Overall	8.90	11.80 (.000)	2.16 Strong

Effect size based on Cohen et al. [53]: Weak (0.00-0.20), Modest (0.21-0.50), Moderate (0.51-1.00), Strong (>1.00)

The outcomes clearly distinguish the performance improvements between the experimental and control groups. Only conceptual understanding showed a statistically significant improvement in the control group, with gains in chemical formula writing remaining relatively small. However, there was a decrease in chemical naming, and overall performance did not much increase. On the other hand, the experimental group showed notable improvements in all areas, including conceptual understanding, writing chemical formulas, and chemical identification, all of which had statistically and practically significant benefits. The overall performance gain of the experimental group was significantly higher, indicating the efficacy of the ION learning model. This shows that the experimental group's model significantly improved student learning and performance compared to the control group. In this learning model, the activities catered to the identified needs and difficulties of the students when learning about the topics. It was shown that when activities are tailored towards specific and actual needs, they help students succeed in further chemistry topics [54-55].



(A) (B)

Fig. 3. Raincloud plots of the (A) control and (B) experimental groups.

These findings are further supported by the raincloud plots shown in Figure 3. The individual pre-test data connect with the post-test data points of the control group. The difference in the entry and exit levels of the control group shows scattered data points that lie primarily along the pre-test scores. The box plot for the pre-and post-tests confirms the closeness of the entry and exit scores. This is also shown in the density plot generated, where the scores' density mostly overlaps the entry and exit scores. Chemistry lectures are successful because they convey fundamental ideas. A competent lecturer may provide a solid foundation for additional learning in laboratories and conversations by clearly explaining complicated concepts and utilizing examples and visuals to aid chemical understanding [6,56].

The results of the experimental group show that individual data points show an increase in the pre-test and post-test scores. The box plots support this through the higher difference in the height of the whiskers. Its density plot shows the post-test distribution of scores towards the higher end, and only a minimal overlap is seen between the entry and exit data. Regan et al. [53] explain that Chemistry is a conceptually complex subject. Students cannot chunk the abstract and complicated nature of the subject, and this has to be addressed through targeted intervention programs. It has been proven that the students who took the intervention instruction showed a gain in their performance scores and were prepared to take higher-level Chemistry topics. This indicates that participation in an intervention in chemistry successfully targets the issue of the subject's complicated nature [6-15].

Table 8 shows the results of combining the control and experimental groups by determining the difference between their main gains, with the corresponding t-test and Cohen's d.

The comparative analysis in Table 8 reveals that the experimental group did substantially better than the control group in every aspect. The experimental group made significant progress in writing conceptual understanding, chemical formula writing, and chemical naming. The most significant improvement was seen in chemical naming. There were notable improvements in overall performance as well. The statistical significance of the mean gain differences across the groups suggests that the ION learning model had a noteworthy effect on the learning and performance of the students. The effect sizes prove these enhancements were noteworthy and highly relevant in real-world applications. Using the introduce, operate, and network lesson structure paved the way for the students to experience the lesson through the appropriate integration of teaching strategies that made the lessons easier to grasp and understand [31, 56].

Table 8. Comparative analysis between the mean gains of the two groups

Aspect	Difference between Mean Gains	t (p)	Cohen's d
Conceptual Understanding	1.27	2.76* (.008)	0.71 (Moderate)
Chemical Formula Writing	2.47	3.44* (.001)	0.89 (Moderate)
Chemical Naming	4.80	8.65* (.000)	2.23 (Strong)
Overall	8.53	8.32* (.000)	2.15 (Strong)

Effect size based on Cohen et al. [53]: Weak (0.00-0.20), Modest (0.21-0.50), Moderate (0.51-1.00), Strong (>1.00)

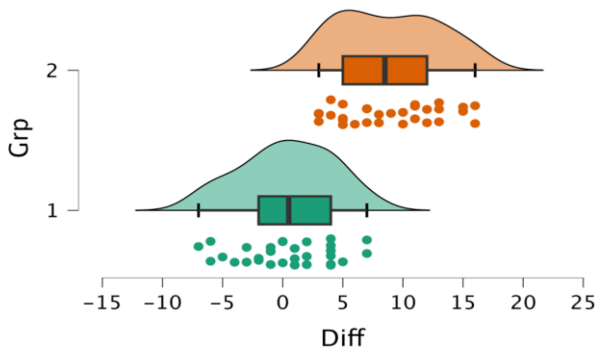


Fig. 4. Raincloud plot of the mean gains of the control and experimental groups.

For the overall comparison between the control and experimental groups, the raincloud plot of the mean gains is shown in Figure 4. The difference in the height of the control and experimental groups shows a substantial difference between these groups. The clusters of data are more scattered in the control group. The other group shows more precise data points. This supports the findings of a strong effect of the ION learning model on the experimental group. This indicates that the ION learning model can help correct misconceptions and assist in understanding some problematic chemistry topics, like the strategies mentioned in the scoping review in the present study's analysis phase [28-36] and other innovative strategies such as EMBER-R [57], metacognitive skills-based instructional materials [58], and dual situated learning model [59].

Students' Feedback on the ION Learning Model

Table 9 showcases quantitative feedback from the students on their level of engagement, comprehension, and interaction with the ION learning model.

Table 9. Students' level of engagement, comprehension, and interaction

Feedback	Mean (SD)	Description
Engagement	3.75 (0.26)	High
Comprehension	3.76 (0.23)	High
Interaction	3.73 (0.24)	High

Legend: Very low (1.00-1.80), Low (1.81-2.60), Moderate (2.61-3.40), High (3.41-4.20), Very high (4.21-5.00)

Students exposed to the ION learning model rated their level of engagement as high, as seen in Table 9. These students participated in the activities designed for them and found themselves more focused and interested in the lessons they were learning. This is consistent with the findings of Swartbooi et al. [60], who implemented a hands-on chemistry intervention program that provided a highly engaging classroom environment that positively influenced the student's attitudes and interest toward chemistry.

Most of the experimental group students rated their comprehension level as high. Their confidence in understanding the lesson and explanations was digestible, leading them to grasp the concepts well. This supports the findings of Wu and Shah [30] that when students are aided in the visualization of chemical representation that connects to the conceptual component of the lesson, it helps reduce errors and overcome difficulties in Chemistry, hence understanding the lesson. The ION learning model was designed with varied strategies that enhanced the visualization of the formula writing and naming process.

Similarly, the students rated their interaction level high when instructed using the ION learning model. They feel comfortable when asking for help and clarification. Their communication is encouraged and helps them understand the topics even further. The degree of their collaboration and participation is engaging because it makes them interact with the activities designed in the ION lessons, especially the ones that make them talk and help one another. Premo et al. [34], Harper [61], Abualrob et al. [62], and Anand [63] supported this idea of the use of technology in promoting communication and collaboration among teacher-student and student-student. Teachers who maximize technological strategies give students varied chances of content exploration.

Students Experiences during the ION Learning Model Implementation

This study also explored implementing the ION learning model in teaching formula writing and naming of inorganic compounds, focusing on students' experiences. The thematic analysis of participants' responses to the semi-structured interview about their experiences implementing the learning model yielded three themes, as highlighted in Table 10.

Table 10. List of themes, subthemes, and frequencies derived from students' experiences

Themes	Subthemes	Frequency
Experiences with Step-by-Step Learning	1. Guided journey through structured steps	5
	2. Personalized learning pace	3
Challenges Encountered	1. Confusion over ion charges	6
	2. Initial adaptation difficulty	2
Opportunities for Engagement and Understanding	1. Active participation and practical application	4
	2. Skill enhancement through problem solving	4

Theme 1: Experiences with Step-by-Step Learning. The first theme delves into participants' experiences as they navigate the structured steps of the ION learning model. Participants expressed appreciation for the clear guidance offered by the model, noting its effectiveness in breaking down complex processes into manageable steps. This theme highlights the personalized learning pace afforded by the model, allowing individuals to engage with concepts at their speed. This theme is supported by two sub-themes, including (1) a guided journey through structured steps and (2) a personalized learning pace.

The students emphasized how this step-by-step guidance facilitated their learning process. The model provides a clear path for students to follow by breaking down complex concepts into manageable steps. Participant 8 highlighted this aspect, describing the model as breaking down the process into clear steps, stating, *"Learning to write formulas and name ionic compounds becomes easy. We were taught the process in clear steps, making it easier to understand and remember."* This structured approach simplifies the learning process and enhances comprehension by ensuring students grasp each component before moving on to the next [64-65]. It also helps reduce cognitive load, improve retention, and make learning more accessible and enjoyable for students of all levels [66-67].

Aside from this, the students appreciated the flexibility of the lesson, which allowed them to learn at their own pace. Participant 1 highlighted the importance of this aspect, emphasizing the freedom to practice and understand concepts independently, stating, *"The aspect that contributed the most towards my understanding of the subject was that I can practice it on my own, and I was given that freedom to ponder around and understand the subject in my own pace."* This personalized approach caters to individual learning styles and preferences, empowering students to take ownership of their learning journey. The model enables participants to delve deeper into concepts and consolidate their understanding by removing the pressure to keep up with a predetermined pace. This autonomy fosters a sense of empowerment and self-efficacy among students, contributing significantly to their comprehension of the subject matter. According to Zhou [68], students with high self-efficacy are more likely to engage in autonomous learning behaviors, such as setting goals, choosing study materials, and evaluating their results in Chemistry.

Theme 2: Challenges Encountered. This theme explores the challenges participants encounter in their engagement with the learning model. Despite its benefits, students and teachers need help with problems such as confusion over ion charges and initial adaptation difficulties. This theme underscores the importance of addressing these challenges to optimize the learning experience. The subthemes included (1) confusion over ion charges and (2) initial adaptation difficulty.

Despite the benefits of the model, the students encountered challenges, particularly regarding understanding ion charges. Participant 2 highlighted this difficulty, acknowledging the initial confusion surrounding ion charges, *"One main challenge is understanding the charges of ions, which can be confusing at first."* This challenge is inherent in the complex nature of ionic compounds, where the interaction of positively and negatively charged ions determines compound formation. Understanding these charges is fundamental to writing accurate formulas and naming compounds. Salleh et al. [69] revealed that students often need help with basic concepts like ions, chemical formulas, and equations, which are fundamental to learning topics related to salts and compounds. However, the abstract nature of ion charges can pose a barrier to comprehension, requiring additional support and clarification [15,69-70].

Another challenge faced by students was the initial adjustment to the learning process. Participant 8 noted, "*Getting used to the new way of learning Chemistry might be tricky initially. Recognizing ions could be tough initially, but with practice, it gets easier."* Recognizing ions and comprehending their combinations could feel tricky at first. This difficulty may stem from the unfamiliarity with the model's approach or the complexity of the subject matter itself. Adapting to new learning methodologies requires time and practice, and participants may need help applying the model effectively, as in other experimental studies in chemistry education [6-15,28-36]. However, with perseverance and support, students can gradually overcome this challenge and gain proficiency in utilizing the model to enhance their understanding.

Theme 3: Opportunities for Engagement and Understanding. The third theme focuses on the model's active engagement and collaborative learning opportunities. Participants highlight the value of hands-on activities and group discussions in deepening their understanding of the subject matter. This theme underscores the importance of fostering a supportive learning environment where students can actively participate and learn from one another. Subthemes for this theme included (1) active participation and practical application and (2) skill enhancement through problem-solving.

Students were provided opportunities for active engagement and hands-on learning experiences. Some participants highlighted how the model enabled them to actively engage with the topic of formula writing and naming of ionic compounds. Participant 3 mentioned, *"The opportunity that the Chemistry class offers me is that it enables me to actively engage in learning how to write and name ionic compounds." The model fosters a more profound understanding and retention of concepts by incorporating practical activities and discussions*. Through hands-on application, participants can reinforce their learning and develop essential skills for real-world application. Hands-on experience, including lab experiments, simulations, and fieldwork, allows students to apply theoretical concepts to real-world situations, enhancing their understanding and skill development [6-9,71-72]. This active participation enhances the overall learning experience and enables participants to gain a deeper insight into the subject matter.

Engaging with the learning model enhances participants' problem-solving skills, enabling them to analyze complex scenarios involving ionic compounds. Participant 3 elaborated, *"Additionally, my problem-solving skills to analyze different situations of the ionic compounds and apply appropriate answers to the formula writing and naming of ionic compounds were enhanced."* This shows how the model enhances their problem-solving skills by enabling them to analyze different situations and apply appropriate solutions. This skill is invaluable in chemistry, where studying and solving problems is essential. Tsaparlis [73] and Ahmad et al. [74] mentioned that solving problems effectively is fundamental in chemistry education, requiring students to develop strong problem-solving skills, connect theoretical knowledge with practical applications, and systematically approach challenges. The learning model equips students with the skills they need to succeed academically and professionally by providing practical application and problem-solving opportunities in Chemistry.

4. Conclusions

This study investigated the effectiveness of the Introduce-Operate-Network (ION) learning model, developed through the ADDIE model, in improving student comprehension and proficiency in formula writing and compound nomenclature in chemistry education. As evident in the results, the approach's content validity was verified through expert assessment, while its reliability demonstrated its efficacy in assessing student performance accurately and consistently. The comprehensive findings from both quantitative analysis and qualitative insights underscore the effectiveness of the ION learning model in enhancing student understanding and skills in formula writing and compound nomenclature. Quantitative analysis revealed significant improvements in conceptual understanding, chemical formula writing, and compound naming among students instructed using the ION learning model compared to those in the control group. These results indicate the model's ability to address learning objectives and promote skill development in challenging chemistry topics.

Furthermore, the qualitative analysis provided valuable insights into the experiences of students and teachers with the ION learning model, highlighting its strengths in fostering a structured learning environment, personalized pace, and opportunities for active engagement and collaboration. Students reported increased engagement, focus, and confidence in understanding the subject matter, underscoring the model's positive impact on learning experiences. Overall, the ION learning model is a promising pedagogy for enriching student comprehension in chemistry education. Its demonstrated effectiveness suggests the potential for refinement and adaptation to overcome challenges and expand its utility to diverse scientific domains. By embracing continuous evolution and adapting instructional methodologies like the ION model, teachers can craft immersive and compelling learning experiences tailored to accommodate varied learning styles, fostering more profound engagement with scientific concepts across disciplines.

Author Contributions

All the authors conceptualized the study, including its methodology and investigation. JM Sanchez conducted the formal analysis, interpretation, and visualization of the results, while JK Taneo and M Narca discussed the results further. All authors prepared the draft and revised and edited the manuscript based on the journal's comments.

References and Notes

[1] Lombardi, D.; Shipley, T. F. *Psychol. Sci. Public Interest* **2021**, *22*, 8. [Crossref]

[2] Sugano, S. G. C.; Nabua, E. B. *Int. J. Instruct.* **2020**, *13*, 881. [Crossref]

[3] Bernardo, A. B.; Limjap, A. A.; Prudente, M. S.; Roleda, L. S. *Asia Pac. Educ. Ver.* **2008**, *9*, 285. [Crossref]

[4] Tijap, H. C.; Malamdag, J. E.; Paz, P. M.; Pelgone, A. J. O. *Jurnal Pendidikan MIPA* **2022**, *23*, 123. [Crossref]

[5] Mangubat, F. M.; Picardal, M. T. *Int. J. Instruct.* **2023**, *16*, 15. [Crossref]

[6] Sanchez, J. M. P. *Kimika* **2017**, *28*, 22. [Crossref]

[7] Sanchez, J. M. P. *Sci. Educ. Int.* **2018**, *29*, 214. [Crossref]

[8] Sanchez, J. M. P. *Int. J. Learn Teach Educ. Res.* **2021**, *20*, 48. [Crossref]

[9] Opona, A. J.; Sanchez, J. M. P.; Bondoc, K. *Kimika* **2022**, *33*, 21. [Crossref]

[10] Sanchez, J. M.; Fernandez, M. J.; Abgao, J. M.; Sarona, H.; Asenjo, S. B.; Guiroy, B.; Oponda, A. J. D.; Vale, X. M. *Kimika* **2021**, *32*, 34. [Crossref]

[11] Cerna, E.; Cortes, S. F.; Padilla, K. J.; Pepino, C. A.; Guion, J. B.; Gomez, S. D.; Taniola, J. V.; Sumalinog, K.; Dinawanao, C.; Callanga, C.; Sanchez, J. M. *Jurnal Pendidikan Progresif* **2023**, *13*, 597. [Crossref]

[12] Rivera, G. M.; Sanchez, J. M. P. *Orbital: Electron. J. Chem.* **2020**, *12, 276*. [Crossref]

[13] Navarro, C.; Torrefranca, A.; Mangolare, R.; Celades, J. R.; Mabuting, R. V. V.; Tugao, J. E.; Ybañez, J. J. C.; Picardal, M. T.; Sanchez, J. M. P. *Kimika* **2023**, *34*, 47. [Crossref]

[14] Guion, J. B.; Sumalinog, K.; Gomez, S. D.; Cortes, S. F.; Padilla, K. J.; Pepino, C. A.; Taniola, J. V.; Cerna, E.; Sanchez, J. M. *Kimika* **2023**, *34*, 36. [Crossref]

[15] Cotiangco, E. N.; Huraño, N. J.; Sodoso, E. R.; Sumagang, M. G.; Jumao-as, J. J.; Canoy, J.; Picardal, M.; Sanchez, J. M. P. *Orbital: Electron. J. Chem.* **2024**, *16*, 125. [Crossref]

[16] Deleña R.; Marasigan, A. C. *Int. J. Acad. Stud. Technol. Educ.* **2023**, *1*, 156. [Crossref]

[17] Shana, Z.; Abulibdeh, E. S. *J. Technol. Sci. Educ.* **2020**, *10*, 199. [Crossref]

[18] Kapici, H. Ö. *Int. J. Res. Educ. Sci.* **2023**, *9*, 134. [Crossref]

[19] Available from: https://edu.rsc.org/ideas/six-tips-for-teaching-chemical-formulas/3009095.article. Access April 2024

[20] Available from: https://www.hmhco.com/blog/importance-of-hands-on-science-activities. Access April 2024

[21] Available from: https://www.edutopia.org/article/engaging-high-school-science-lessons/. Access April 2024

[22] Available from: https://www.acs.org/education/policies/middle-and-high-school-chemistry.html. Access April 2024

[23] Available from: https://www.deped.gov.ph/wp-content/uploads/2019/01/Science-CG_with-tagged-sci-equipment_revised.pdf. Access April 2024

[24] Spatioti, A. G.; Kazanidis, I.; Pange, J. *Inf.* **2022**, *13*, 402. [Crossref]

[25] Cronbach, L. J. *Psychometrika* **1951**, *16*, 297. [Crossref]

[26] Sanchez, J. M. P. *J. Res. Environ. Sci. Educ.* **2024**, *1*.

[27] Braun, V.; Clarke, V. *Qual. Res. Psychol.* **2006**, *3*, 77. [Crossref]

[28] Logerwell, M. G.; Sterling, D. R. *Sci. Teach* **2007**, *74*, 27. [Link]

[29] Mulvey, B. *Sci. Teach.* **2016**, *83*, 44. [Link]

[30] Wu, H. K.; Shah, P. *Sci. Educ.* **2004**, *88*, 465. [Crossref]

[31] Schmidt, S. J. *J. Food Sci. Educ.* **2021**, *20*, 166. [Crossref]

[32] Chew, S. L. *J. Food Sci. Educ.* **2014**, *13*, 65. [Crossref]

[33] Lukman Abdul, R. L.; Utina, R.; Husain, R.; Masri, K. U.; Muhammad, R. K.; Panigoro, C. *Eurasia J. Math. Sci. Technol. Educ.* **2023**, *19*. [Crossref]

[34] Premo, J.; Cavagnetto, A.; Davis, W. B. *CBE-Life Sci. Educ.* **2018**, *17*. [Crossref]

[35] Jabeen, F.; Afzal, M. T. *J. Educ. Educ. Dev.* **2020**, *7*, 119. [Crossref]

[36] Smetana, L. K.; Bell, R. L. *Int. J. Sci. Educ.* **2012**, *34*, 1337. [Crossref]

[37] Bobek, E.; Tversky, B. *Cogn. Res. Princ. Implic.* **2016**, *1*. [Crossref]

[38] Agustian, H. Y.; Finne, L. T.; Jørgensen, J. T.; Pedersen, M. I.; Christiansen, F. V.; Gammelgaard, B.; Nielsen, J. A. *Rev. Educ.* **2022**, *10*. [Crossref]

[39] Kahsay, T. T.; Berhe, G. G.; Tesdamariam, G. M. *Afr. J. Chem. Educ.* **2024**, *14*, 128. [Link]

[40] Reyes, R. L.; Villanueva, J. A. *J. Chem. Educ.* **2024**, *101*, 1106. [Crossref]

[41] Box, M. C.; Dunnagan, C. L.; Hirsh, L. A.; Cherry, C. R.; Christianson, K. A.; Gibson, R. J.; Wolfe, M. I.; Gallardo-Williams, M. T. *J. Chem. Educ.* **2017**, *94*, 164. [Crossref]

[42] Wu, M. Y. M.; Yezierski, E. J. *Chem. Educ. Res. Pract.* **2022**, *23*, 287. [Crossref]

[43] Kang, J.; Keinonen, T. *Res. Sci. Educ.* **2018**, *48*. [Crossref]

[44] Frey, R. F.; McDaniel, M. A.; Bunce, D. M.; Cahill, M. J.; Perry, M. D. *CBE-Life Sci. Educ.* **2020**, *19*. [Crossref]

[45] Hagos, T.; Andargie, D. *Sci. Educ. Int.* **2022**, *33*, 383. [Crossref]

[46] Pietarinen, T.; Vauras, M.; Laakkonen, E.; Kinnunen, R.; Volet, S. *J. Comput. Assist. Learn* **2019**, *35*, 334. [Crossref]

[47] Taborada, J. C.; Sanchez, J. M. P. *Kimika* **2020**, *31*, 11. [Crossref]

[48] Gonzales, G. H. A.; Despe, K. B.; Iway, L. J.; Genon, R. J. S.; Intano, J. O.; Sanchez, J. M. P. *J. Educ. Technol. Instruct.* **2023**, *2*, 1. [Link]

[49] Byusa, E.; Kampire, E.; Mwesigye, A. R. *Heliyon* **2022**, *8*. [Crossref]

[50] Chans, G. M.; Portuguez Castro, M. *Comput.* **2021**, *10*. [Crossref]

[51] Agwu, U. D.; Nmadu, J. *Chem. Educ. Res. Pract.* **2023**,

24, 688. [Crossref]

[52] Espinosa, A. A. *Int. J. Learn Teach Educ. Res.* **2014**, *2*, 91. [Link]

[53] Cohen, L.; Manion, L.; Morrison, K. R. B. Research Methods in Education. Routledge, 2007

[54] Regan, A.; Childs, P.; Hayes, S. *Chem. Educ. Res. Pract.* **2011**, *12*, 219. [Crossref]

[55] Easa, E.; Blonder, R. *Chem. Educ. Res. Pract.* **2024**. [Crossref]

[56] Achimugu, L. *J. Contemp. Educ. Res.* **2018**, *2*. [Crossref]

[57] Jusniar, J.; Effendy, E.; Budiasih, E.; Sutrisno, S. *Int. J. Instruct.* **2021**, *14*, 85. [Crossref]

[58] Narusdin, H.; Azizah, U. *Jurnal Pendidikan IPA Indonesia* **2020**, *9*, 125. [Crossref]

[59] Kurniawan, M. A.; Rahayu, S.; Fajaroh, F.; Almuntasheri, S. *J. Sci. Learn* **2020**, *3*, 99. [Crossref]

[60] Swartbooi, T. B.; Rubidge, G.; Gibbs, M. D.; Ferg, E. E. *South Afr. J. Chem.* **2022**, *76*, 102. [Crossref]

[61] Harper B. *J. Res. Technol. Educ.* **2018**, *50*, 214. [Crossref]

[62] Abualrob, M.; Nazzal, S. *Contemp. Educ. Technol.* **2020**, *11*, 55. [Crossref]

[63] Anand, S. A. A. *Materials Today Proceed* **2021**, *47*, 240. [Crossref]

[64] Dayal, P. D.; Ali-Chand, Z. *New Zealand J. Educ. Stud.* **2022**, *57*, 425. [Crossref]

[65] Sarıtaş, D.; Özcan, H.; Adúriz-Bravo, A. *Sci. Educ.* **2021**, *30*, 1289. [Crossref]

[66] Hartman, J. R.; Nelso, E. A.; Kirscher, P. A. *Found Chem.* **2022**, *24*, 239. [Crossref]

[67] Kala, N.; Ayas, A. *J. Turk Sci. Educ.* **2023**, *20*, 468. [Crossref]

[68] Zhou, N.; Fischer, C.; Rodriguez, F.; Warschauer, M.; King, S. *J. Comput. High Educ.* **2020**, *32*, 505. [Crossref]

[69] Salleh, M. F. M.; Rauf, R. A. A.; Saat, R. M.; Ismail, M. H. *Eur. J. Sci. Math. Educ.* **2023**, *11*, 392. [Crossref]

[70] Taber, K. S. *Found Chem.* **2020**, *22*, 309. [Crossref]

[71] Hu-Au, E.; Okita, S. *J. Sci. Educ. Technol.* **2021**, *30*, 862. [Crossref]

[72] Salame, I. I.; Makki, J. *Interdiscip. J. Environ. Sci. Educ.* **2021**, *17*. [Crossref]

[73] Tsaparlis, G. Problems and Problem Solving in Chemistry Education: Analysing Data, Looking for Patterns and Making Deductions. Royal Society of Chemistry, 2021.

[74] Ahmad, Z.; Ammar, M.; Sellami, A.; Al-Thani, N. J. *J. Chem. Educ.* **2023**, *100*, 1796. [Crossref]

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