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Android-based Audio-Visual Comics in Enhancing Conceptual Understanding and Motivation of Chemistry Concepts

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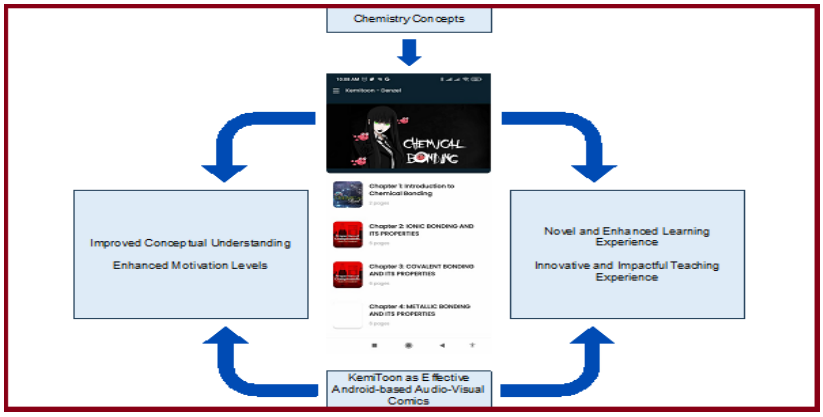
The complexity of chemistry arises from its abstract nature and heavy reliance on mathematical concepts, posing significant challenges for students. Combining technology with traditional teaching, comics are used as one of the educational multimedia options because of their unique ability to infuse humor, a way to convey scientific information that can captivate people's attention and interest. This study investigated the effectiveness of Android-based audio-visual comics in teaching chemical bonding among two groups of Grade 9 science class students in a public secondary school in Cebu, Philippines. Using a causal-comparative design, a 20-item pretest-posttest method was used to measure the extent of the effect of the integration on students' conceptual understanding; meanwhile, an adapted version of the Chemistry Motivation Questionnaire-II (CMQ-II) to measure the increased motivation of the students. A semi-structured interview was utilized to gather qualitative data for teaching experiences, while a focus group discussion was used to collect students' experiences. Quantitative results suggested that students' conceptual understanding significantly improved after exposure to the instructional material. Meanwhile, the four components of students' motivation significantly increased, specifically intrinsic motivation, self-efficacy, self-determination, and grade motivation. Moreover, students' learning experiences using the instructional material discussed in the focus group discussion revealed that it helped them understand chemistry topics better and become more motivated to learn chemistry. Thus, science educators may consider using the instructional material in teaching science concepts to enhance motivation and conceptual understanding. Furthermore, future studies would have to consider the appropriateness and suitability of the instructional material in other subject areas and grade levels.

Graphical abstract



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1. Introduction

Educators today can enhance their teaching methods by incorporating multimedia, such as comics, into classrooms [1]. Combining text, images, videos, and animations, these digital resources provide an interactive platform that effectively captures students' attention. In science education, comics and cartoons have gained popularity among teachers seeking innovative approaches. However, challenges persist, with the Philippines' below-average performance in science highlighting the need for improved educational strategies. The 2022 results of the Programme for International Student Assessment (PISA) show that the Philippines ranked third to last among the poorest-performing countries in science [2]. Notably, Chemistry, one of the branches of science, is recognized as a complex subject because it is too abstract and mathematical for students [3]. Comprehending chemistry's conceptual and symbolic aspects is a fundamental skill that students must cultivate to develop critical thinking abilities. Furthermore, educators emphasize the importance of systematic and inductive teaching, utilizing various modes of representation [4-6].

Comics are used as one of the educational multimedia options because of their unique ability to infuse humor, making them promising ways to convey scientific information that can captivate people's attention, interest, and enjoyment, covering the spectrum of fascination, joy, and the utility of science [7]. Landherr [8] initially found the effectiveness of integrating comics into courses. It shows that the integration of comics has substantially improved students' interest and confidence. At the same time, student understanding has either held steady or also enhanced depending on how the comics are integrated. Several studies show the effectiveness of comics as a helpful resource in comprehending scientific concepts, such as in the fields of thermodynamics, physics, and biology. For instance, a study by Mamolo [9] demonstrated a positive result of using comics as instructional material. The study found a gradual increase in motivation, which would help develop students' critical and analytical thinking skills in mathematics. Moreover, according to Badeo and Koc [10], there was a significant improvement in motivation and conceptual comprehension of physics among students when using a comic-based learning module in science instruction.

Audio-visual elements enhance learning by stimulating the brain and improving information retention. Traditional comics rely on reading and analyzing images, but research suggests that adding audio narration can increase motivation, vocabulary acquisition, and learning retention [11]. To bridge the gap and evaluate the effectiveness of audiovisual comics in chemistry education, the app KemiToon, a research-made android-based audio-visual comics app, provided teachers with instructional material and promoted independent learning by offering an engaging medium for students of all reading levels. Combining technology with the usual way of teaching, this initiative aims to improve motivation and conceptual understanding, making chemistry more engaging and effective for Filipino learners. Hence, this study aimed to determine the pre-test and post-test scores, level of motivation, and learning and teaching experiences evident during the exposure to android-based audio-visual comics in Chemistry.

Related Literature

Gruenberg, Director of the Child Study Association of America [12], viewed comics and cartoons as valuable, citing numerous examples of how comics could effectively teach various subjects. She noted, "There is hardly a subject that does not lend itself to presentation through this medium." However, despite their potential to enhance learning, comics have often faced societal backlash as it is detrimental to literacy [8]. It has been argued that comics hinder reading comprehension, limit imagination, and cause eyestrain [13]. Consequently, Wertham [14] condemned comics for depicting violence, suggestive themes, and their supposed negative impact on children. Additionally, he argued that comics promoted illiteracy, violence, racial stereotypes, and homosexuality, among other issues [15], and described their use in education as "an all-time low in American science" [16]. However, his claims were criticized for lacking scientific evidence [17].

Despite past criticisms, comics can be valuable teaching aids in science education, encouraging student involvement and critical thinking when properly deployed [18]. Modern science education employs various teaching methods, among which comic strips play a significant role. Estacio [19] highlights the positive impact of comic strips as instructional materials on student performance, particularly in enhancing understanding through visual representations. Additionally, a study by Enteria and Casumpang [20] confirms the effectiveness of cartoons in improving student performance, even in challenging subjects like Physics. While comics facilitate productive classroom engagement and have the cognitive potential for student motivation and retention [21-22], the broader scope lies in their application within science education. Combining images and text, comics make learning more engaging and can shift students' perspectives on education [23]. When crafted according to sound pedagogical principles, comics support learning by contextualizing stories and creating meaningful connections to students' lives [24]. They encourage active participation and critical thinking between panels, incorporating literature and painting to enrich the learning experience [25]. Comics offer a promising environment for science education, providing effective tools to teach complex concepts and prevent misconceptions [26-27]. They engage students in hypothetical scenarios and improve science literacy by enhancing opportunities for reading and discussion [28]. Moreover, educational comics simplify science concepts, making them visually appealing and aiding knowledge retention, thus enhancing learning [25,29-30].

Badeo's study [31] found that science comics as a learning medium increased students' conceptual understanding. Based on binary coding theory, which supports the importance of visuals in cognitive operations, it pertains to the development of recall and recognition by verbally and visually presenting information [32]. Students establish a connection between the text and the image, participating wholeheartedly in the teaching-learning process while reading the comics. Science comics ease the complexity and abstraction of scientific concepts, providing retention of essential understandings because they are visually appealing to learners [33]. Science comics, therefore, prepare learners through inquiry-based methods, especially in student-centered classrooms, where the teacher carefully facilitates the activity [34]. According to Özdemir [35], comic stories simplify scientific concepts, and their visual nature increases retention in the long run. Da Silva et al. [36] suggested two ways to use comics in the classroom: allowing students to

reflect on their experiences and structuring the comics from a theoretical point of view. Furthermore, Sari and Lubis [37] found that Android chemistry comics are suitable for chemistry learning and increase student learning outcomes. Hence, educational comics are a viable medium for instruction in science concepts, providing quality information transfer and achieving learning outcomes.

Evidentiary support shows that learners find it more amusing to read visual-verbal materials than solely verbal learning mediums; hence, motivational factors relatively affect it. As Lin et al. [38] put it, learners enjoy reading comic books more than textbooks because they find visual narratives amusing rather than monotonous texts. Comics can be utilized as powerful media in interpreting knowledge and applying science literacy because images are more stimulating and appealing than explaining scientific facts solely [39]. Supplementing science comics in the classroom potentially attracts learners to learn science and motivates those with poor comprehension skills to become more adept due to the simple language used [40]. Consequently, integrating comics into teaching and learning has enhanced students' motivation and active participation [34]. Students with high intrinsic motivation in reading science comics showed better academic competence than those without [31]. The pedagogical use of comics poses advantages such as efficient motivation for lessons, focus aids, and integration development in various literacies [34]. Therefore, comics opportunely allow learners to discover a higher level of understanding of scientific concepts that transcend beyond the confines of the classroom.

Moreover, according to Muzumdar [41], combining text and illustrations improves understanding and memory retention, wherein comics offer this valuable tool [42]. Incorporating dynamic and interactive elements in the comics, such as the addition of audio narration, improves the learning experience when used intentionally. Additionally, audio is essential for visually impaired students and other textual disorders like dyslexia [43]. Thus, using audio-visual elements aligns with dynamic visualizations in integrating comics into science teaching [44]. Although the instructional process takes on a new dimension when audio-visual integration is used [45] and provides engaging learning, teachers must use audio-visual materials [46].

The use of animation content in the multimedia approach of teaching chemistry has many potential as it is straightforward to incorporate into the learning process. Both teachers and students can benefit significantly from computer-aided teaching methods with animation content when the required infrastructure or suitable laboratory conditions are unavailable [47]. However, when multiple external representations, defined as combining written text, computer animation, graphical representation, and narration, are used in teaching chemistry [4-6,48-49], those of poor quality can inhibit the students' learning progress. It can cause misconceptions [50] and distractions to students when animations are used in chemistry lessons [51]. Yet, if appropriately used as instructional material, this can reduce the notion of chemistry as a problematic subject, reduce mental effort, and improve self-efficacy [52].

To address this problem, this study aims to evaluate the benefits of integrating Android-based audio-visual comics into chemistry classes. When crafted according to pedagogical principles and adequately deployed, comics' visual appeal and integration of texts and images, especially when combined with audio elements for an enriched learning experience, enhances conceptual understanding and promotes motivation, making learning enjoyable. Moreover, integrating technology into instruction delivery is essential in developing 21st-century skills. Specifically, using a mobile application to make the comics paperless, marking students' quizzes and questionnaires, and as online storage for scores can provide many advantages for the teacher and students [53]. Thus, this paper explores the promising and engaging features of integrating an android-based audio-visual comics instructional material as a medium for chemistry education, overcoming earlier criticisms with demonstrated pedagogical benefits.

2. Material and Methods

A mixed-method approach using the quasi-experimental design with embedded narrative inquiry was used, and the quantitative method took a primary role. In contrast, the qualitative method provided additional insights or support. It employed the pretest-posttest method that assessed the effectiveness of KemiToon, na Android-based audio-visual comics application, in enhancing students' conceptual understanding. The control group was exposed to the usual teaching instruction using a PowerPoint presentation, while the experimental group had the integration of the KemiToon app.

The integration was conducted at a public high school in Cebu City, Philippines. Respondents of the study were two groups of grade nine students from special science classes (n=61). One group of 30 students was assigned as a control group, and the usual method of instruction was using PowerPoint presentations. In contrast, the other group, with 31 students, belonged to the experimental group in which the integration of the KemiToon app was administered. The implementation of the study lasted for one week during the second quarter of School Year 2023-2024, excluding the administration of pretest, posttest, and interview. The participants were selected through convenience and purposive sampling for the quantitative and qualitative aspects of the study, respectively. Since the survey was heavily based on the Curriculum Guide and Most Essential Learning Competencies (MELCs) of the Department of Education (DepEd), the study's time frame was also based on the school calendar of DepEd. For the quantitative part of the study, convenience sampling was used to select the school and students to participate due to the practical considerations of accessibility and availability, ensuring that the study could be conducted efficiently within the specified time frame and resources. The conditions for participant selection included (1) two classes with an equal number of students, (2) both classes under the guidance of the same Science teacher, and (3) students who belonged to a particular science class.

Meanwhile, purposive sampling was explicitly employed during the qualitative part of the FGD. Purposive sampling involves intentionally choosing participants for a study based on specific criteria or qualifications that align with the study's objectives. The selection of student participants for the FGD were selected through the students' reflection and preferred learning style. Those who identified themselves as audio, visual, or both/all were chosen to be interviewed. This approach ensured that the participants in the FGD had relevant, firsthand experience with the KemiToon app integration, thus providing rich and focused insights into its effectiveness and impact on student learning. While convenience sampling was chosen due to easier accessibility

and availability, it is acknowledged as a limitation of the study. The results might differ if conducted in different schools, as educational environments and student populations can vary widely. Additionally, results could vary if the survey were conducted in another school year due to potential changes in curriculum or student characteristics over time.

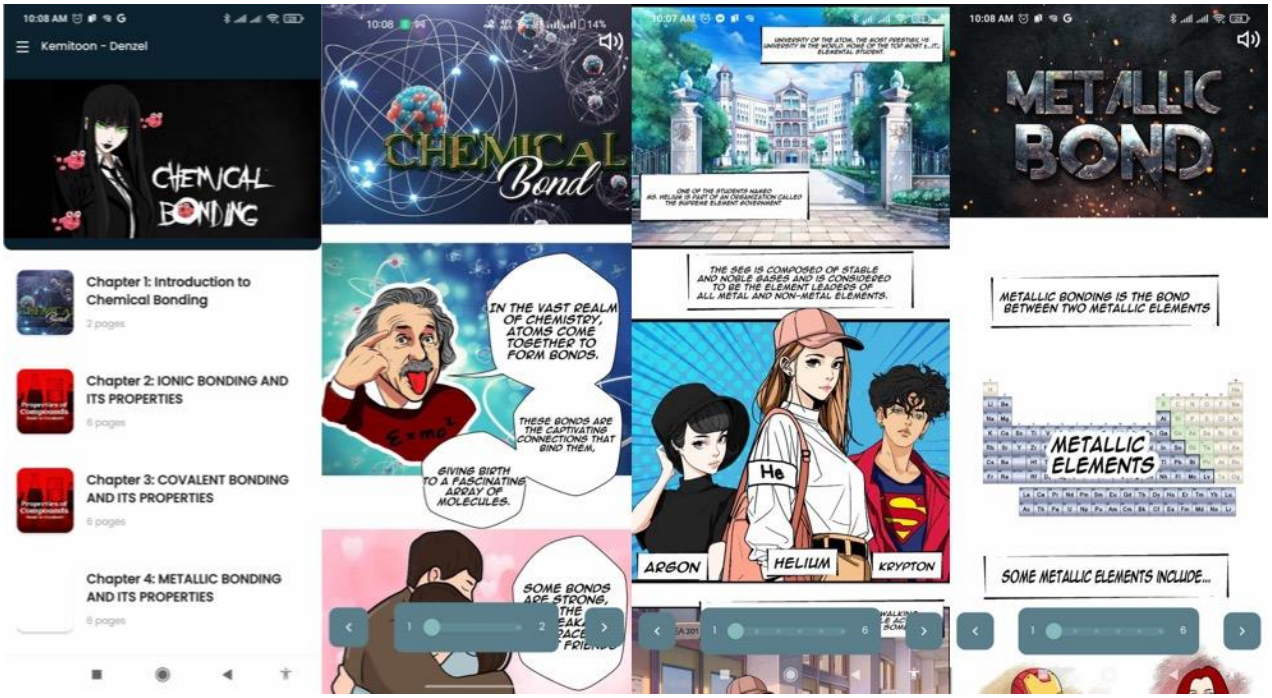

Fig. 1. KemiToon interface.

In the quantitative manner of the study, a researchers-made 20-item test was employed to assess the student's conceptual understanding of chemistry concepts, specifically chemical bonding. The test questions were validated and underwent pilot testing with a Cronbach's alpha value of 0.74. Meanwhile, a Chemistry Motivation Questionnaire-II (CMQ-II) was modified [54] to measure students' motivation to learn Chemistry concepts. For the qualitative aspect, a Focus Group Discussion (FGD) guide questionnaire and a semi-structured interview guide were utilized to examine the students' learning experiences and teachers' teaching experiences, respectively. The FGD guide questionnaire, composed of eight questions, and the interview guide, consisting of six questions, were both validated by two Science teachers. The researchers also utilized a 5E lesson plan model for the control group and in teaching chemical bonding by integrating the android-based audio-visual comics for the experimental group.

Before starting the intervention, an ethical clearance was secured to ensure that the ethical standards set by the University were observed. Likewise, all the letters addressed to the academic offices were obtained to ensure protocols were followed. Afterward, pre-testing was conducted. A unified 20-item multiple-choice test was given to the control and experimental groups to examine the participants' prior knowledge and behavior about the topic. Additionally, a motivation questionnaire was employed to test the student's level of motivation before using the KemiToon app. Then, the app was integrated into the class. The lesson plans, which were structured according to the 5E learning cycle model, were utilized by the cooperating teacher for both the control and experimental groups. Students from the experimental group accessed the KemiToon application, an Android-based audio-visual comics Integrated Instruction, where they read the comics for Chemical Bonding–Ionic Bonding, Covalent Bonding, and Metallic Bonding and each of its properties. Audio-visual learners could turn on the audio feature in the application for a more meaningful learning experience. The control group used the same lesson plan as the experimental group; instead of using the KemiToon app, they proceeded with their usual delivery of lessons using a PowerPoint presentation. The intervention lasted for four weeks and was based on the specified learning competencies reflected on the MELCs of DepEd. The specified learning competency was to recognize different compounds (ionic or covalent) based on their properties, such as melting point, hardness, polarity, and electrical and thermal conductivity. At the end of the integrated instruction, the participants took the exact unified 20-item multiple-choice test parallel to the pre-test, which served as the post-test.

After administering the post-test, the CMQ-II was given to the experimental group of learners to determine if there was a significant difference in the motivation to learn chemistry concepts after using the KemiToon app. Furthermore, Selected participants in the experimental group participated in the FGD, which assessed their learning experiences. Meanwhile, the teachers conducted a semistructured interview with the researchers to explore their teaching experiences after integrating the KemiToon app into the lesson delivery.

The quantitative data were subjected to the Shapiro-Wilk test to determine whether the data sets were normal. Mishra et al. [55] state that Shapiro-Wilk's test is more appropriate for testing the normality for small sample sizes (<50 samples).

Based on Table 1, the pretest and posttest performances of the control and experimental groups obtained W-values greater than 0.900 and p-values greater than .05. These values indicate that the data are not significantly different. Hence, the data sets are normally distributed. With this, parametric tests were appropriate for the study. The test performances were

analyzed and described using descriptive statistics such as mean and standard deviation. The pretest and posttest performances were compared using t-tests for paired samples.

Table 1. Normality of the pre-test and post-test performances

Group	Test Performance	*W*-value	*p*-value
Control	Pre-test	0.963 ^{ns}	.360
	Post-test	0.962 ^{ns}	.340
Experimental	Pre-test	0.969 ^{ns}	.503
	Post-test	0.936 ^{ns}	.065

^{ns} Not significant at α=.05

In contrast, the mean gains of the control and experimental groups were compared through t-tests for independent samples. Additionally, the data on motivation levels were analyzed using the same descriptive statistics stated above. All inferential tests were conducted at 95% confidence levels, and p-values less than .05 were considered significant. Statistical analysis and treatment were done using the software Statistical Packages for Social Sciences (SPSS) 26.

Braun and Clarke's [56] reflexive thematic analysis method was used to analyze the qualitative data from the focus group discussions for students and the semistructured interviews. The criteria for coding students' learning experiences of the KemiToon were the following themes: Novel Learning Approaches, Enhanced Understanding and Learning of Chemistry Concepts, Motivation for Audio and Visual Learners, and Students' Overall App Engagement. Meanwhile, the teachers' teaching experiences of the KemiToon as instructional material have the following themes: Teaching Method Enhancement, Enhanced Engagement and Interest, Impact on Learning Outcomes, and Challenges Faced/ Suggestions for App Improvement.

Adherence to ethical principles is essential in research agreements to ensure ethical guidelines. Before participating in the study, participants are encouraged to sign a voluntary consent form about Kemitoon apps. This study strictly adhered to research ethics protocols, as evidenced in the CNU-ERC certification (727 / 2023-10 Cotiangco).

3. Results and Discussion

Test Performances of the Students

The students were given pre-tests and post-tests to determine their entry and exit levels of conceptual understanding in Chemistry. Their scores are shown in Table 2.

Table 2. Students' test performances.

Group	Test	Performance			Description [a]
		Mean (SD)	Equiv. %	Transmuted	
Control	Pre-test	9.67 (3.28)	48.35	70	Did not meet expectations
	Post-test	12.60 (2.22)	63.00	76	Fairly satisfactory
Experimental	Pre-test	11.00 (2.18)	55.00	73	Did not meet expectations
	Post-test	17.36 (1.89)	86.80	91	Outstanding

[a] Based on DepEd's system: Below 75 (Did not meet expectations), 75-79 (Fairly satisfactory), 80-84 (Satisfactory), 85-89 (Very satisfactory), 90 and above (Outstanding).

As shown in Table 2, both control and experimental groups initially exhibited similar pre-test means, revealing that both groups did not meet the expected chemistry competencies on chemical bonding. These baseline data suggest a prevailing gap in the foundational Chemistry knowledge and understanding, particularly concerning the concepts of chemical bonding. With this, teachers must formulate targeted interventions and innovative strategies to address this inadequate baseline understanding as foundational Chemistry is essential to life [57-58].

After exposure to targeted interventions like PowerPoint-integrated lectures in the control group and KemiToon-integrated classes in the experimental group, both groups manifested improvements in their pre-test performance levels. After the pedagogical exposure, the control group's performance became reasonably satisfactory, showing moderate progress. This result could be attributed to the lectures' structured nature and visual aids concreting concepts and fostering tangible connections between theory and real-world applications. Science lectures can convey chemistry information via digital or online media to enhance students' conceptual understanding [59]. PowerPoint presentations can improve learning outcomes and provide good responses from students in Chemistry [60].

On the other hand, the experimental group's performance skyrocketed to outstanding performance, showing a high level of progress. This finding reflects the immersive audiovisual nature of KemiToon, which transforms concepts into captivating and relatable narratives. Through this, theory and real-world applications are intertwined, leading to progressive learning in Chemistry. Electronic comics are valid and practical instructional materials for learning Chemistry [61-62].

The t-test for dependent samples was employed to compare the pre-test and post-test performances of the control and experimental groups. Table 3 summarizes the results, gleaning whether the mean gains were significant in each group.

Table 3. Mean gains in students' conceptual understanding.

Group	Pre-test	Post-test	Mean Gain	*t*-value	*p*-value
Control	9.67	12.60	2.93	8.572*	.000
Experimental	11.00	17.36	6.36	27.111*	.000

* Significant at α=.05

According to Table 3, the control group manifested a significant mean gain after the exposure to PowerPoint-integrated lectures in the Chemistry class. This finding underscores the efficacy of lectures in the 21st century but with innovations like presenting them through PowerPoint

presentations that preserve lectures' structured and organized nature. Consequently, adding visual aids like illustrations and diagrams augments cognitive processes such as enhanced retention, understanding, and summary of foundational yet complex chemical concepts. Due to this, the students improved despite the initial conceptual challenges in chemical bonding, leading to moderate progress in their conceptual understanding. With this, the control group had an enriched learning experience even within the traditional pedagogical paradigm of lectures [59-60]. PowerPoint-integrated lectures enhance students' comprehension and motivation in Chemistry [63]. When integrated with other interactive features, student conceptions lead to effective conceptual understanding [64].

Similarly, the experimental group also showed a significant mean gain after the exposure to KemiToon integrated classes in Chemistry. This result indicates that the innovations brought about by the android-based audio-visual comics transformed students' pre-test conceptions into better post-test outcomes. These innovations, such as immersive audio-visual storylines and interactive elements, led to a better grasp of chemical bonding. Through this, an engaging learning environment fosters motivation, engagement, and conceptual assimilation among the students, leading to outstanding progress in their conceptual understanding. Hence, the experimental group was empowered to be immersed in the learning process facilitated by the innovative nature of KemiToon in Chemistry [61-62]. Comics-based instruction can improve cognitive processes, enthusiasm, and learning outcomes [65-66]. Metacognitive skills can also be trained using the innovative features of digital comics [67]. When integrated into different modalities, comics can be legitimate and appropriate for teaching and learning chemical concepts [68-69].

To test which pedagogical intervention is more effective in teaching chemical bonding concepts, the *t*-test for independent samples was conducted. Table 4 shows the results of comparing the mean gains of the said interventions.

Table 4. Comparison between mean gains.

Group	Mean Gain	Difference	*t*-value	*p*-value	Cohen's *d*
Control	2.93	3.42	8.297*	.000	2.400
Experimental	6.36				(Large)

* Significant at α=.05

Table 4 shows that the mean gain of the experimental group is significantly higher than that of the control group. This result means that using the KemiToon app is more effective than the PowerPoint lectures in Chemistry. The innovations in the app, like immersive audio-visual storylines, interactive elements, and engaging features, go beyond traditional teaching strategies. Due to this, the students experienced a contextualized and engaging learning environment conducive to optimum learning of Chemistry concepts. Rather than just mere memorization, the students had consistent construction of meaning constructions between theory and real-world application due to the authentic instructional delivery [67,70]. Instead of knowledge receivers, the students were able to engage with the content and learning process in general because of the interactive and engaging elements such as multimedia, vivid graphics, and compelling visuals; this characteristic of the KemiToon caters to diverse learning modalities, leading to more enriched and adaptive Chemistry learning experience [71]. There is also a sense of autonomy among the students because the app allows them to navigate the chemical bonding concepts at their own pace; this autonomy fosters the student's critical thinking and reflective practice toward mastering the said foundational knowledge and understanding [72-73]. Integrating meaningful interaction, engaging app elements, and personalized learning modality led to a better grasp of Chemistry concepts and improved conceptual understanding of the mobile audio-visual interactive instructional material [61-62,68-69].

Furthermore, the effect size is significant due to KemiToon being used in the chemistry class. This effect size establishes the transformative potential of the Android app in fostering an immersive, adaptive, and enriched learning environment capable of improving the student's understanding of Chemistry concepts, including chemical bonding. Compared with the PowerPoint lectures, the KemiToon app innovates the traditional education paradigm into a more student-centered and profound cognitive engagement in Chemistry classes [61-62,68-69, 71,73].

Motivation Levels of Students

The level of motivation of students exposed to the KemiToon integrated classes in Chemistry was investigated. The results of the *t*-test for paired samples before and after the said pedagogical exposure are presented in Table 5.

Table 5. Students' motivation before and after exposure to KemiToon

Aspect	Before	After	*t*-value	*p*-value
Intrinsic Motivation	3.27 (0.59) Moderate	4.25 (0.65) Very high	3.664	.000
Career Motivation	2.47 (0.80) Low	3.07 (0.78) Moderate	3.874	.000
Self-Determination	3.05 (0.84) Moderate	4.23 (0.62) Very high	4.025	.000
Self-Efficacy	2.88 (0.44) Moderate	4.27 (0.55) Very high	4.112	.000
Grade Motivation	3.25 (0.79) Moderate	4.46 (0.70) Very high	4.199	.000

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

Table 5 presents consistent results showing a significant improvement in students' motivation before and after exposure to the KemiToon app in learning chemical bonding concepts. Their intrinsic motivation significantly increased, indicating that the students' interest in and curiosity about chemistry increased while using KemiToon in their class. Furthermore, intrinsic motivation refers to what comes from within by being genuinely interested or being challenged by a particular goal [74-75]. It is expressed by 'curiosity,' 'a sense of purpose,' 'a feeling of competence,' 'autonomy,' etc. [76]. Notably, a high intrinsic motivation demonstrated by students

is associated with improved academic performance, more positive views of their academic ability, and reduced academic anxiety from early childhood through adolescence [77].

Similarly, their career motivation also significantly improved, signifying that the student's prospects for Chemistry or other science-related careers were cultivated because of KemiToon's capability to connect theory with real-world applicability and relevance. This aspect is similar to the grade motivation aspect but has a more concrete or tangible goal: the career [78]. However, this aspect scored the lowest effect size among the assessed motivation. Because students haven't started considering their career paths yet at this early level, studying science will lead to a concrete goal as their profession [31].

Aside from intrinsic and career motivation, the results significantly transformed students' self-determination and self-efficacy. As a theory, self-determination has proven effective when satisfying three basic psychological needs for relatedness, competence, and autonomy, suggesting students' engagement with scientific learning [79]. The students' self-efficacy also significantly improved after exposure to the KemiToon app. This motivation level highlights that through the students' self-assessment, they could perform the learning process to achieve the learning goals [80]. Scoring an increase in self-efficacy has a relational rise in the student's awareness of being motivated to improve new abilities and persevere when a learning process gets too uneasy. Among the assessed motivation levels, grade motivation scored the highest. This finding supports previous studies [81-82], which identified that extrinsic motivations such as getting good grades, "means to an end," can serve as motivators in learning science. They also found that grade motivation scored the highest among the assessed motivation levels.

Moreover, these significant findings regarding the motivation levels of the students can be attributed to the adaptive and personalized nature of the KemiToon integrated classes, wherein students can use the app according to their unique cognitive preferences and pace, for example, turning on or off the narration audio or going back to previous pages. The unique blend of immersive multimedia storylines and real-world applicability of the Android app resulted in better motivational outcomes. These outcomes lead to student character development, such as caring for the surrounding environment, interacting with others, and having high curiosity [83]. Due to this, the app has nurtured their self-directed attributes and enhanced their confidence in learning chemistry concepts and their competence in answering questions related to the said concepts. With personalized learning modalities and an adaptive learning environment, the students enhanced their motivation to learn and eventually improved their conceptual understanding of the chemical concepts [18,26].

Learning Experiences using KemiToon

Student transcripts resulted in four emergent themes: (1) Novel learning approaches, (2) Enhanced understanding and learning of chemistry concepts, (3) Motivation for auditory and visual learners, and (4) Overall app engagement.

Novel Learning Approaches: Students' reactions to introducing the KemiToon app into chemistry lectures were overwhelmingly favorable, signaling a dramatic shift from traditional teaching approaches. P1's expression of shock perfectly captures the feeling: "I was shocked because I had never heard of another app that gave chemistry lessons through comics." This innovative method skillfully incorporates instructional material into engrossing comic narratives, stimulating students' interest and curiosity—especially regarding complex subjects like chemical bonding. Students frequently complimented KemiToon for its usefulness and educational value. This compliment highlights KemiToon's ability to present complex chemistry concepts in approachable and engaging multimedia formats, demystifying abstract principles and facilitating profound conceptual understanding. P2 confirmed, "The app is handy to us, students... and helpful because it is very informative." Furthermore, students' initial skepticism—as articulated by P5—was replaced with gratitude when they saw the app's engagement, highlighting its capacity to ignite sincere enthusiasm and interest in chemistry teaching.

Additionally, P3 noted that incorporating audio components into KemiToon's comic stories improved the learning process, saying, "The addition of audio enhances the experience, as I easily learn from seeing pictures." This creative fusion of visual and auditory stimuli broke traditional boundaries and encouraged multisensory engagement, retention, and comprehension. KemiToon's innovative methodology and incorporation of multimedia components enabled a rich, flexible, and engaging learning environment that promoted deep conceptual understanding, involvement, and academic success in chemistry education, especially about chemical bonding concepts [72].

Enhanced Understanding and Learning of Chemistry Concepts: Students' understanding of complex concepts like chemical bonding has been transformed by introducing the KemiToon app into chemistry lessons. KemiToon uses audio-visual comics to improve student engagement and intellectual experience. P3 acknowledged KemiToon's thorough explanations, "I've learned so many things about chemistry like chemical bonding, especially also on metallic bonding because of the explanations every after storyline." P2 emphasized the app's usefulness by saying, "It helped me better understand chemical bonding and provided memorable examples." These comments highlight KemiToon's capacity to create an immersive learning environment that supports academic excellence in chemistry education.

P6 highlights KemiToon's transformative power even further, explaining how it improves conventional teaching strategies by making chemistry approachable and pleasurable. P6 said, "The app motivates me, making learning fun and easy." Testimonials like this support KemiToon's novel approach, which combines multimedia materials and engaging narratives to encourage students' sustained engagement, deep conceptual understanding, and intrinsic motivation. KemiToon's unique teaching nature added to its effectiveness in raising students' academic performance and igniting a desire to learn chemistry for the rest of their lives. This strategy highlights KemiToon's practical and pedagogical usefulness in fostering informed, empowered, and inspired learners within the scientific domain by demystifying abstract concepts and fostering curiosity [84].

Motivation for Audio and Visual Learners: Students' learning experiences have been significantly improved by the KemiToon app's integration of audio and visual elements, which is especially advantageous for individuals who prefer auditory and visual learning methods. Student testimonials, such as that of P3, demonstrate how well the software creates an engaging learning environment, expressing, "I feel motivated to learn since I hear what I'm reading and seeing…very effective to me since I rarely read and it

influences me well since I am a lazy reader." P6 also highlighted the app's appropriateness for visual learners, praising its captivating storylines and artistic styles that enhanced understanding and chemistry excitement, "I am more a visual learner, so this app helped me a lot in learning chemistry, and it also motivated me since I love reading and also the art style of the characters fit my standard."

This teaching innovation aligns with recent empirical studies and pedagogical ideas that highlight the use of multimedia materials, including comic books, in educational contexts. These results are consistent with KemiToon's clever combination of audio components and visual storytelling, which offers a robust platform that raises motivation, engagement, and academic achievement. This alignment highlights KemiToon's capacity to foster a supportive and enriching learning environment that will enable students in the science subject. Incorporating audio-visual features in KemiToon meets and surpasses students' expectations, promoting deep conceptual understanding, persistent engagement, and intrinsic motivation. This strategy, based on pedagogical research and actual data, highlights KemiToon's revolutionary influence in raising a new generation of knowledgeable, capable, and motivated chemical students [10].

Overall App Engagement: Students have expressed great appreciation for using the KemiToon app in chemistry lectures, especially for its interactive features and general level of engagement. Such testimonies highlight the app's ability to transform learning into an engaging and captivating journey. P4's recollection vividly captures this sentiment: "...make the learning content more memorable, and I find myself genuinely interested in exploring each topic because of how entertaining this is." "...since it uses anime drawings, it helped me to understand the topic because it is fun to use due to the anime," P5 said, echoing the same attitude. According to research showing the entertainment value of comics in science education, visually attractive features like anime illustrations improve comprehension and ignite students' excitement and attention [85].

Additionally, student comments highlight how crucial flexibility and accessibility are in instructional technology. The app's accessibility across multiple platforms was highlighted by P1 in her statement, "...not all my classmates have an Android phone, so having it also to iOS is a good idea." This awareness of various technological environments ensures broader access and inclusivity, enhancing the app's reach and impact within educational settings. Moreover, P5's proposal for additional comic chapters validates the effectiveness of employing comics to satisfy learning objectives and maintain interest in chemistry education by reflecting students' demand for increased content and ongoing involvement [86-87].

Students' good experiences and feedback demonstrate the successful integration of the KemiToon app into chemistry teaching. Its captivating visual components, cross-platform compatibility, and ability to accommodate various learning requirements validate its revolutionary potential in promoting a rich, approachable, and compelling learning environment. KemiToon is a valuable tool for encouraging academic achievement, motivation, and long-term involvement in the scientific subject because it adheres to pedagogical concepts and considers students' preferences.

Teaching Experiences in Integrating KemiToon

With similar results as the learning experiences, the teachers' experiences were described according to four emergent themes: (1) Enhanced teaching method, (2) Increased engagement and interest, (3) Impactful learning outcomes, and (4) Challenges and suggestions.

Enhanced Teaching Method: Incorporating the KemiToon app into chemistry lessons has improved student learning experiences and transformed how teachers educate. Instructors have seen a more efficient use of classroom time due to a more streamlined teaching procedure. This efficiency was emphasized by T1, who said, "It shortens my discussion period and allows more time for problem-solving and assessment, which is beneficial in the teaching process." These observations show that the app's interactive features and exciting content create a more concentrated and productive learning environment, freeing teachers to devote more time to real-world applications and assessments.

Teachers have also noticed that the software can adapt to modern student's preferences and learning styles. This acknowledgment highlights KemiToon's ability to align with modern pedagogical approaches and address students' evolving needs and preferences. T2 emphasized the app's relevance, noting, "I can see that the students are more indulged in the lesson due to its attractiveness, being 'in with the generation' of the students, aesthetic, educational, and it boosts the interest of the students." By incorporating visually appealing and relatable content, the app creates a more dynamic and engaging learning environment that encourages student excitement and participation. Using the KemiToon app in chemistry education has improved student engagement and allowed professors to employ their instructional strategies more effectively. As a revolutionary instrument for supporting excellent teaching methods, developing academic achievement, and creating a dynamic and engaging learning environment within science subjects, it is validated by its alignment with modern student preferences and educational aims [65,73].

Increased Engagement and Interest: Incorporating the KemiToon application into chemistry lessons has significantly increased student involvement and revitalized enthusiasm for learning among the pupils. Instructors have seen a noticeable change in the classroom dynamics, with T1 noting that students enjoy the app: "It is proven from my two science classes that they do enjoy the app." The feedback the students provided highlights the app's effectiveness in grabbing their interest and fostering a more responsive and dynamic learning environment. The students did exhibit beneficial behavioral changes after using the app.

KemiToon's ability to seamlessly blend entertainment with educational content, thereby resonating with students' preferences and learning styles, is highlighted by T2, who echoed this sentiment and emphasized the app's transformative impact on students' academic enthusiasm and engagement: "They responded positively to the app, which changes their behavior in terms of interest in learning, which is very helpful in the learning process." The app's engaging content and user-friendly design provide an engaging and immersive learning environment that promotes long-term engagement and improves knowledge of the complex chemistry subject. Incorporating the KemiToon app into chemistry teaching has improved student engagement and sparked a passion for learning, significantly enhancing instructors' classroom experiences. Its creative fusion of instructional and entertainment elements corresponds with today's students' interests, encouraging engagement, zeal, and a high caliber of work in science subjects. KemiToon is a valuable tool for creating a dynamic, engaging, and productive

learning environment for students because of its student-centered design and pedagogically solid methodology [65,73].

Impactful Learning Outcomes: Teachers have seen a good shift in students' attitudes and engagement levels due to integrating the KemiToon app into chemistry lessons, which has resulted in noticeable increases in learning results. "Hopefully, they will conduct this app more in regular classes, which could be more realistic in the teaching and learning process because it changed students' behavior in learning the subject content," T1 said in response to this observation. This testimony highlights KemiToon's ability to improve the effectiveness of instruction delivery by encouraging students' increased interest and passion for chemistry subjects. They are more engaged in learning.

"Real-life examples (like relationships) relating to the topic were given, which gives us the upper hand in explaining the concept," T2 said, emphasizing the app's effectiveness in contextualizing complex topics through relatable real-life examples. These pedagogical strategies resonate with contemporary educational insights, highlighting the importance of contextual learning and relevance in facilitating comprehension and retention. Relatable examples, like relationships, help students better understand abstract topics and improve their ability to make the connection between theory and practice. This enhances students' overall learning experience and academic performance. Incorporating the KemiToon app into chemistry instruction has improved student interest, engagement, and comprehension, which has substantially impacted learning outcomes. Instructors' observations underscore their revolutionary influence on teaching approaches, stressing their effectiveness in placing material in context, encouraging active learning, and creating a lively and captivating learning atmosphere. KemiToon's creative methodology and adherence to educational best practices make it invaluable for improving student learning and encouraging high standards in science education [61-62,68-69].

Challenges and Suggestions: Introducing the KemiToon app into chemistry lessons has presented educators with benefits and obstacles in their quest to maximize student learning. Teachers have faced challenges that call for attention, even if the app is a creative audio-visual instruction platform that fits nicely with the current technological landscape. T1 clarified these difficulties by highlighting the necessity of keeping students' attention on academic material rather than extraneous details: "One of my first concerns is the students' interest, particularly in science. Their attention is on me and my willingness to learn. Pay attention to the contents rather than the character and color. Try to avoid the "relationships" on the app, even though it's great. It might persuade younger pupils to engage in this activity." With this, the audio-visual comics may hinder optimum learning in Chemistry [40].

As for logistical issues, T2 identified potential diversions and device accessibility, saying, "One of the challenges is the availability of mobile phones since not all of the students have the resources." Another problem would be that if they are not constantly watched, they might use their phone to play mobile games rather than access the app. Additionally, it would be great if the software could be used offline. These findings emphasize how crucial it is to consider real-world limitations and other distractions when implementing mobile-based instructional tools. User feedback indicates that to address these issues and improve the app's usefulness, offline accessibility features should be included, and material should be enhanced to ensure it aligns with learning goals. This will help students learn in a more concentrated and efficient manner. While the KemiToon app presents a promising framework for improving chemistry instruction through captivating audio-visual materials, educators have noted particular difficulties with device accessibility, possible outside distractions, and content alignment. The key to maximizing the app's potential and creating a focused, enriched learning environment that satisfies the varied needs of students in the scientific field while aligning with pedagogical objectives is to address these issues through student-centered improvements and strategic implementation strategies [33,88].

4. Conclusions

Test scores, motivation, and general learning experiences significantly improved after introducing the KemiToon app into chemistry lessons. The experimental group outperformed the control group in post-tests, while both groups improved. Some studies from different fields support these results [7-8,10,26,84] that using comics can effectively enhance students' understanding and motivation when used as a tool when integrated into the classroom. It has been demonstrated that using comics to teach science can help students learn and understand the subject better. They are a helpful instrument for quickly, appropriately, and effectively conveying much information [26]. The KemiToon's novel elements, such as its engrossing audio-visual storytelling, increased student engagement and promoted deep conceptual understanding. This result closely aligns with the educational principles described in the study of Dietrich et al. [89]. Comparable to how elements of popular culture, such as video games and movies, captivate students and connect science with contemporary interests, Android-based comics provide a potent medium for involving young audiences in science. The findings emphasize the potential of Android-based audio-visual comics as a transformative tool in chemistry education, aligning with broader trends in science comics and educational materials [90].

Additionally, the app offered a more dynamic and effective learning environment aligned with contemporary teaching approaches. In light of the study's findings, teachers are urged to use multimedia resources like KemiToon to enhance learning. Educators should use a blended learning strategy that blends traditional lectures with interactive online resources to accommodate different learning styles. Furthermore, improving these tools' compatibility with other platforms and guaranteeing offline functionality might increase their usefulness in various educational contexts.

Although the study shed light on the effectiveness of the KemiToon app, there are some significant limitations to be aware of. The study's scope may have limited its generalizability to other areas or themes because it was primarily focused on particular principles in chemistry. Furthermore, it is essential to interpret the results cautiously because they could have been influenced by outside factors like students' prior knowledge and technology accessibility. Future research could expand on this study by investigating KemiToon's broader applicability across various disciplines and grade levels. Further insights may be obtained by examining the long-term impacts of incorporating such multimedia technologies on students' academic performance and motivation. Refining cutting-edge teaching tools would also involve looking at the best ways to handle technology

accessibility and guarantee content relevance in various educational contexts.

Supporting Information

Supplementary Material- 20-item Test Questionnaire.

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Author Contributions

EN Cotiangco, NJ Huraño, ER Sodoso, MG Sumagang, JJ Jumao-as, J Canoy, and M Picardal conceptualized the study, including its methodology and investigation. JM Sanchez conducted the formal analysis and interpretation of the results. All authors prepared the draft and revised and edited the manuscript based on the journal's comments.

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