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Enhancing Students' Interest in Learning Through Augmented Reality: A Case Study of Using Delightex in Chemical Bonding Teaching

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Augmented Reality (AR) is increasingly recognized as a powerful tool in education, particularly due to its ability to enhance student engagement and support the visualization of abstract scientific concepts. In the context of chemistry education, AR can provide interactive 3D models that help learners better understand topics that are traditionally considered challenging. This study aims to examine the impact of AR-based instruction using the Delightex platform on students' learning interest in the Chemical Bonding unit of a high school chemistry course. A total of 120 tenth-grade students in Ho Chi Minh City, Vietnam, participated in the study. They were divided into an experimental group ($n = 60$), which received AR-enhanced lessons, and a control group ($n = 60$), which followed traditional teaching methods. Learning interest was assessed through pre- and post-intervention surveys and tests. The results indicate that students in the experimental group exhibited significantly higher levels of learning interest compared to those in the control group ($p < 0.05$). Despite these positive outcomes, the study acknowledges certain limitations related to technological constraints, teacher readiness, and the time required to design AR resources. Future research should explore strategies to improve AR content quality, examine long-term learning effects, and explore effective strategies for integrating AR with pedagogical practices in chemistry classrooms.

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Introduction

Augmented Reality (AR) has emerged as a significant and groundbreaking factor in various industries and services worldwide. In the field of education, AR is increasingly recognized as an innovative pedagogical tool that enhances active learning by providing interactive and immersive experiences, thereby bridging the gap between abstract concepts and real-world applications. With the ability to display 3D models, videos, images, and sounds in real space, AR not only facilitates students' direct engagement with knowledge but also enhances their learning interest and motivation (Chen, 2006; Dave, Chaudhary, & Upla, 2019; Lee, 2012).

Learning interest is a crucial factor in educational psychology, directly influencing students' cognitive processes, motivation, and academic performance (Silvia, 2006). From the 17th to the 19th century, educators such as Herbart emphasized the role of interest in education (Krapp & Prenzel, 2011). Factors affecting learning interest include family background, teaching methods, and the learning environment (Anigbo & Idigo, 2016; Zaiton & Hishamuddin, 2012). Numerous studies have proposed strategies to enhance learning interest, highlighting the role of teachers and instructional approaches (T. T. C. Nguyen, 2008; H. G. Nguyen, 2014). Learning interest is manifested through students' active participation, curiosity, and improved academic performance (Jansen, Lüdtke, & Schroeders, 2016; Singh, Misra, & Srivastava, 2017).

The Chemical Bonding topic provides fundamental knowledge about molecular structures, explaining the formation and properties of substances. This topic aids students in developing scientific reasoning skills while serving as a foundation for studying specific chemical compounds. However, conveying abstract concepts such as chemical bonding and molecular structures through traditional teaching methods can be challenging. To address the diverse learning needs and levels of students, integrating various teaching methods, especially AR technology, can support both teachers and students in effectively approaching this topic (Vietnam Ministry of Education and Training, 2018). Although AR has been proven to be effective in supporting teaching and learning processes, research on its specific application in teaching Chemical Bonding remains limited.

This study was conducted within the context of Vietnam's high school education system, specifically in the 10th-grade chemistry curriculum. Applying AR technology in teaching not only helps students visualize 3D molecular models more easily but also enhances interactivity and has the potential to improve their learning interest. Consequently, this study aims to address the following research questions:

(1) How does the application of AR in teaching the Chemical Bonding topic influence students' learning interest?
(2) How is the correlation between academic performance and other dimensions of learning interest?

Literature review

Augmented reality and Delightex platform

Augmented Reality technology, introduced and developed more than 60 years ago, allows computer-generated images to closely simulate the physical properties of the real world (Zhou, Duh, & Billinghurst, 2008). This study applies Azuma's (1995) definition of AR, which describes it as a system or technology that (a) combines real and virtual images, (b) allows real-time interaction, and (c) appears in three-dimensional space (i.e., the real world). According to Craig (2013), AR technology works through two main steps. Step 1: The system collects data from the physical environment and generates the corresponding virtual data to determine the state of both the real and virtual worlds. Step 2: Elements from the virtual world are displayed and seamlessly integrated into the real world, creating the perception that they are part of the surrounding environment. This process repeats continuously to keep up to date on the interaction between the two worlds.

Initially, AR was developed for computers with screens and cameras before being integrated into mobile devices such as smartphones, tablets, and AR glasses. an essential feature in the design of this technology. Thanks to its ability to integrate virtual elements into the real world to create interactive and immersive experiences, AR is becoming increasingly popular in education, particularly in aiding the visualization of abstract concepts, promoting active learning, and enhancing student engagement (Craig, 2013; Lee, 2012). AR applications have been deployed in many fields such as construction (Webster et al., 2000), medicine (Harders et al., 2007), and commerce (Poushneh & Vasquez-Parraga, 2017).

In chemistry education, AR helps clarify complex concepts such as molecular structure, chemical bonds, and reaction mechanisms (Chen, 2006; Mazzuco et al., 2022). It also allows students to conduct virtual experiments, such as observing the titration reaction between hydrochloric acid and sodium hydroxide (Chen, 2006). Many studies have proven that AR not only enhances interest in learning, but also develops self-learning, supports the assessment process, and improves the quality of chemistry education in general (M. D. Nguyen et al., 2023; Vu, Phung, Nguyen, & Dinh, 2023; Mazzuco et al., 2022). For example, Thai & Nguyen (2020) found that AR has increased students' interest in organic chemistry through interactive 3D models. It is also asserted that AR-enabled teaching helps promote engagement and improve learning outcomes (Olim, Nisi, & Romão, 2024; Silva, Bermúdez, & Caro, 2023).

To make the creation of specialized AR content for chemistry education, many tools and platforms have been developed. Among them, Delightex (formerly known as CoSpaces Edu) is a flexible platform that allows both teachers and students to creatively design their own 3D, virtual reality (VR), and augmented reality environments. With a user-friendly interface, an extensive library of 3D objects, and an intuitive block-based coding system, Delightex does not require users to have in-depth programming skills. This makes the platform a suitable tool for building interactive molecular models, simulating chemical reactions, or designing lessons on periodic tables and ionic bonds, thereby directly solving the challenge of visualizing abstract concepts in chemistry.

Although the potential of AR is widely recognized, classroom implementation still faces limitations such as device limitations, the risk of distractions, and the need for pedagogical compatibility (Elford, Lancaster, & Jones, 2023). Essentially, AR serves as an effective educational tool that enhances students' engagement and motivation in learning chemistry.

Learning interest

Interest is a crucial psychological state in learning, influencing students' cognitive processes, motivation, and academic performance. Studies indicate that interest is characterized by two main conditions: (1) it must be consciously recognized and understood by an individual as meaningful to their life, and (2) it must evoke a distinctive sense of enjoyment or engagement in the individual. In education, learning interest is defined as a student's particular attitude

toward a subject, where they perceive the subject as meaningful and derive pleasure from the learning process (Silvia, 2006).
Learning interest is closely linked to academic performance. It affects students' engagement and ability to explore problems, as well as their progress in academic achievements. Interest can be stimulated through innovative teaching methods, such as the application of AR, which fosters student engagement and active participation in learning activities (Hoffmann, Baumert, Krapp, & Renninger, 1998; H. G. Nguyen, 2014; Thai & Nguyen, 2020). Learning interest is also influenced by factors such as the subject itself and gender differences and should be assessed objectively (Jansen et al., 2016; Kirby, Ball, Geier, Parrila, & Wade-Woolley, 2011; Von, Dörfler, & Artelt, 2014).

Learning interest is typically manifested in five key dimensions: intellectual engagement, emotional involvement, willpower, competency, and academic achievement (Liou, Cheng, Chu, Chang, & Liu, 2023; Singh et al., 2017). Intellectual engagement reflects a student's curiosity and proactive learning behaviours, such as asking questions and seeking additional knowledge. Emotional involvement refers to the positive or negative feelings associated with learning, where high interest often leads to enthusiasm and confidence. Willpower represents perseverance and motivation, helping students persist through academic challenges. Competency relates to a student's self-perception of their abilities, influencing their willingness to engage in learning activities. Finally, academic achievement is the measurable outcome of learning, often reinforcing or being reinforced by learning interest. These dimensions collectively shape students' attitudes and performance in education.

These dimensions provide the foundation for constructing an evaluation tool to assess students' engagement in the Chemical Bonding topic in the 10th-grade chemistry curriculum. Other assessment methods, such as behavioural observation or neuroscience techniques, have been used to measure levels of engagement (Krapp & Prenzel, 2011; Peterson, Baker & McGaw, 2009). However, the most commonly employed and reliable approach in educational research is the use of questionnaires, as they are practical and efficient in measuring students' interest in learning (Duong, Dao, Nguyen, & Do, 2016; Jansen et al., 2016; Kirby et al., 2011; Von et al., 2014).

As outlined in the Literature Review section, this study presents the theoretical framework for the role of AR in fostering interactive teaching and learning. Figure 1 illustrates how AR facilitates the interaction between students and teachers, demonstrating its impact on learning interest and its key dimensions, including intellectual engagement, emotional involvement, willpower, competency, and academic achievement.

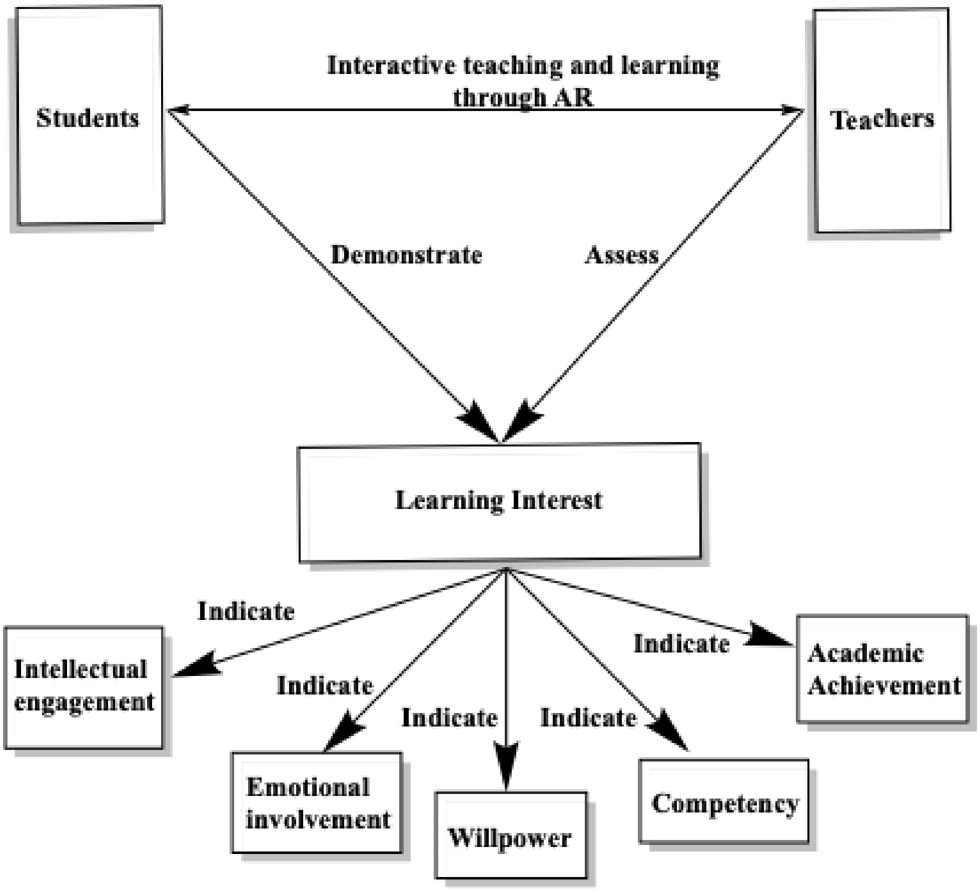

Figure 1. Theoretical Framework

Identify the research gap

While augmented reality has shown effect in enhancing chemistry education, its implementation in specific content areas – such as chemical bonding – is still limited, especially in secondary settings. In addition, the majority of existing research tends to address learning motivation and engagement broadly, without delving into the multifaceted nature of learning interests. Key components such as emotional involvement and competence are often overlooked. These gaps in the literature point to the need for more targeted investigations. This study aims to meet that need by examining the impact of AR – delivered through the Delightex platform – on student academic interest and student academic achievement in the 10th grade chemistry curriculum. The study further explores fundamental aspects of academic interests and their relationship to academic outcomes.

Methodology

Participants

This study uses a convenient sample selection method, selecting grade 10 students from a high school. A total of 120 students were selected based on the school's access and consent to participate in research. These students were divided into two groups: an experimental group of 60 students from 3 classes, a control group of 60 students from 3 other classes.

The division of students into experimental and control groups is not randomly distributed due to administrative constraints and school context. However, the study made efforts to ensure comparability between groups at the beginning of the experiment, including: All participating students had studied Chemistry at the previous level, all participating students had access to AR-compatible mobile devices. The control group and the experiment were taught by the same teacher for 6 weeks. That means, the teacher taught the control group and the experimental group the same content but with different methods, one group using AR and the other using only traditional methods such as lecture, socratic. This design helps ensure that any differences in students' learning interest can be primarily attributed to the integration of AR, as both groups were taught by the same teacher using identical content and instructional duration.

The demographic distribution of participants, including gender composition in each group, is presented in Table 1.

Table 1. Descriptive Statistics of Student Participants

Group	Male Students (%)	Female Students (%)	Total Students (%)
Control	26 (43.3%)	34 (56.7%)	60 (100.0%)
Experimental	35 (58.3%)	25 (41.7%)	60 (100.0%)

Intervention process

The impact process took place over a period of 6 weeks, both groups participated in 12 lessons (each lesson lasted 45 minutes), according to the content and requirements of the topic of Chemistry – Chemical Bonding in Grade 10 – Chemistry General Education Program 2018 in Vietnam. The control group participated in learning activities through Delightex platform. The experimental group was joined with the same content and learning progress, but there was an integration of 07 AR products in the Delightex platform into the lesson content. These AR products allow students to interact with 3D models of atoms, molecules, and types of chemical bonds that match the goals of each lesson in the topic.

To minimize the interference variable, all learning materials were designed and drafted the same in both groups, except that AR was integrated into the experimental group's learning materials. In addition, for the experimental group, students have been instructed to use AR in previous lessons to ensure smooth use of AR. Pre- and post-impact questions and tests are designed the same, managed through Microsoft Teams classroom management software to control test conditions. Furthermore, while the groups were not randomly assigned, baseline statistical tests (independent t-sample tests) were conducted to test the group's equivalence in terms of learning interest and learning outcomes. The results show that most of the dimensions are similar, with only a few minor changes in some sub-domains, which are acknowledged and discussed later in the paper.

These AR-based materials provided students with real-time visualizations of key chemistry concepts, such as atomic structures, molecular bonding, and electron distributions. Table 2 presents a detailed description of the seven AR products, including their code and brief description of their instructional focus. Figure 2 illustrates an example of an AR-based learning module, demonstrating how students could explore molecular geometry and bonding interactions in a virtual space.

Table 2. AR-based learning materials developed for the chemical bonding topic

AR Product Name	Delightex Code	Description	Lesson
The Smart Classroom	NWB-KVB	The product helps to list learning tasks and summarize the learning content with interactive games	Whole the topic
The Strange Rubik	FZG-REU	Products to help students play interactive games	Whole the topic
Oxygen molecule	XPP-NHG	The product helps visualize the process of bond formation and structure of oxygen molecule.	Covalent bond
Ammonia molecule	JMP-DWY	The product helps visualize the process of bond formation and structure of ammonia molecule.	Covalent bond
Methane molecule	WUH-WSD	The product helps visualize the process of bond formation and structure of methane molecule.	Covalent bond
Orbital	BDH-VZZ	The product helps visualize the shape of orbitals and the process of orbital hybridization	Covalent bond
Ionic bond	PCX-FWK	The product helps visualize the process of ionic bond formation	Ionic bond

Figure 2. AR-Based Learning Materials for the Experimental Group

Instruments

To evaluate students' learning interest, this study employed a quantitative research approach using questionnaires and regular assessments. The questionnaire, developed in Microsoft Forms, consisted of two sections: general information (class and gender) and four constructs measuring learning interest across intellectual engagement, willpower, emotional involvement, and competency, using a five-point Likert scale (Liou et al., 2023; Singh et al., 2017). Each item was rated on a five-point Likert scale (1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree) to assess the degree of students' agreement with statements related to 4 dimensions. The pre-intervention questionnaire was administered before students began the Chemical Bonding topic, while the post-intervention questionnaire was distributed immediately after completion. All data collection was conducted via Microsoft Teams.

Table 3. Observed variables

No.	Indications	References
Intellectual engagement (Cronbach's alpha: 0.831)		
1.	I feel passionate and creative when studying Chemistry	(Liou et al., 2023; Thai & T. M. Nguyen, 2020; Singh et al., 2017)
2.	I am willing to ask and find answers to questions for topics related to chemistry	
3.	I want to learn how to apply chemistry knowledge to practice	
Emotional involvement (Cronbach's alpha: 0.737)		
4.	When I encounter a difficult problem related to Chemistry, I will be patient to find a way to solve it	(Liou et al., 2023; Thai & T. M. Nguyen, 2020; Singh et al., 2017)
5.	When I have problems with Chemistry, I often find information from many sources and synthesize and analyze	
6.	When I failed to study Chemistry, I learned a lesson for myself	
Willpower (Cronbach's alpha: 0.782)		
7.	I feel excited when I come to the Chemistry class	(Liou et al., 2023; Thai & T. M. Nguyen, 2020; Singh et al., 2017)
8.	I feel happy and comfortable in Chemistry class	
9.	I feel excited when I complete the learning tasks in Chemistry	
Competency (pre-intervention) (Cronbach's alpha: 0.862)		
10.	I confidently state the history of the invention of the periodic law and the periodic table of chemical elements	(Vietnam Ministry of Education and Training, 2018)
11.	I confidently describe the structure of the periodic table of chemical elements and state related concepts (cells, periods, groups)	
12.	I confidently stated the arrangement principle of the periodic table of chemical elements (based on the electron configuration)	
13.	I confidently classify elements (based on electron profiles: elements s, p, d and f; based on chemical properties: metals, nonmetals, noble gases)	
14.	I confidently explain the tendency of atomic radius changes in a cycle, in a group (group A) (based on the electrostatic attraction of the nucleus to the outermost electron and based on the number of electron layers increasing in a group from top to bottom).	
15.	I confidently commented and explained the tendency of electronegativity and metallicity and non-metal properties of atoms of elements in a cycle, in a group (group A).	
16.	I confidently comment on the tendency to change the composition and acid/base properties of oxides and hydroxides cyclically. Write illustrative chemical equations.	
17.	I confidently speak The Periodic Law of Chemical Elements	
18.	I am confident in presenting the meaning of the periodic table of chemical elements: The relationship between the position (in the periodic table of chemical elements) and its properties and vice versa.	
Competency (post-intervention) (Cronbach's alpha: 0.942)		
10.	I am confident in presenting and applying the octet rule in the process of forming chemical bonds for group A elements.	(Vietnam Ministry of Education and Training, 2018)
11.	I am confident in presenting the concept and formation of ion bonds (give some good examples following the octet rule).	
12.	I am confident in stating the crystal structure of NaCl and explaining why ionic compounds are usually in a solid state under normal conditions (ionic crystal form).	
13.	I am confident in presenting the concept and get examples of covalent bonds (single, double, triple bonds) when applying the octet rule.	

14.	I can confidently write Lewis formulas of some simple substances.
15.	I am confident in presenting the concept of giving and receiving links.
16.	I can distinguish the types of bonds (non-polar covalent bonds, polarization, ionic bonds) based on electronegativity.
17.	I am confident in explaining the formation of sigma bonds and pi bonds through AO overlap.
18.	I am confident in presenting the concept of bonding energy (covalent).
19.	I am confident that I can install a molecular model, NaCl crystals (according to the available model).

Table 3 presents the system of observed variables according to 4 components of learning interest, including: engagement, emotional involvement, willpower, and competency (pre- and post-intervention). The observational statements are based on previous studies (Thai & Nguyen; Singh et al., 2017), especially the observational statements of the competency variable follow the requirements of the General Education Program in Chemistry of Vietnam 2018, and all are measured by a 5-level Likert scale. The Cronbach's Alpha coefficients were all greater than 0.7, with two variables reaching above 0.9, indicating that the scales are highly reliable and can be used in the study (Hair, Black, & Babin, 2010). This demonstrates that the statements in each group of variables are strongly intrinsically correlated, reflect the characteristics to be measured.

Academic performance was assessed through regular assessments administered after students completed the Chemical Bonding topic. The study developed these assessments using Microsoft Forms, with one pre-intervention test and one post-intervention test. Both tests were administered in a multiple-choice format to assess students' comprehension of the subject matter. The raw scores from these tests were then converted to a 5-point scale to facilitate direct comparison with the other dimensions of learning interest, ensuring consistency in data analysis. Higher scores on this scale indicate greater understanding and mastery of the content.

Data analysis

The collected data were analyzed using IBM SPSS Statistics, applying both descriptive and inferential statistical methods to examine the impact of AR-based instruction on students' learning interest and academic performance.

Descriptive statistics, including mean (M) and standard deviation (SD), were computed to summarize students' responses to the Likert-scale questionnaire measuring intellectual engagement, willpower, emotional involvement, and competency, as well as their scores on the 10-point academic tests. To compare differences between the experimental and control groups, an independent samples t-test was conducted to assess whether AR integration led to statistically significant improvements in learning interest and academic performance.

To evaluate changes within each group over time, a paired samples t-test was performed to compare pre- and post-intervention scores for both learning interest dimensions and academic performance, along with Cohen's d values are also used to determine effect sizes. Additionally, Pearson correlation analysis was used to examine the relationship between students' learning interest and their test performance. Pearson correlation is appropriate because it measures the strength and direction of the linear association between continuous variables. In this context, learning interest is typically assessed using Likert-scale survey data, while academic performance is represented by numerical test scores. By leveraging Pearson correlation, the study offers empirical insights into how different facets of learning interest relate to student achievement, supporting targeted interventions to enhance motivation and performance. A significance level of $p < 0.05$ was set for all statistical tests to ensure the reliability of the findings.

Ethical considerations: This study was conducted in accordance with ethical standards for research involving human participants. Before participation, all students and their parents or legal guardians were fully informed about the purpose, procedures, and voluntary nature of the study. Informed consent was obtained from both students and their guardians, ensuring they clearly understood their rights, including the freedom to withdraw from the study at any point without any consequences or pressure. Participants were assured that their personal information would be kept strictly confidential. All collected data were anonymized immediately after collection to protect individual identities. Throughout the research process, the dignity, autonomy, and well-being of the students were respected and safeguarded.

Results

To assess the impact of AR-enhanced instruction on students' learning interest and academic performance, statistical analyses were conducted to compare the pre- and post-intervention data between the control and experimental groups. Descriptive statistics were first computed to summarize the mean (M) and standard deviation (SD) of students' responses on the learning interest questionnaire and their academic performance scores. This was followed by independent samples t-tests to examine between-group differences, and paired samples t-tests to analyze within-group changes over time. Additionally, Pearson correlation analysis was conducted to examine the relationship between academic performance and other dimensions.

Comparison of pre- and post-intervention data between the control and experimental groups

Pre-intervention

To assess the initial comparability between the control and experimental groups, an independent samples t-test was conducted on pre-intervention data for all dimensions of learning interest, including intellectual engagement, willpower, emotional involvement, competency, and academic performance. As presented in Table 4, no statistically significant differences ($p > 0.05$) were observed for most variables, indicating that students in both groups exhibited similar levels of learning interest before the intervention.

However, a notable exception was found in willpower and intellectual engagement, where the control group demonstrated a slightly higher mean score than the experimental group, with a statistically significant difference. This can be explained by several reasons such as the difference in students' career orientation, the experience of chemistry in the previous class. Nevertheless, the overall comparability between the two groups in other dimensions reinforces the validity of subsequent intervention effects.

Table 4. Independent samples t-test before the intervention for the control and experimental groups

Dimension	M (SD)		t	MD	95% CI		Df	*p
	Control	Experimental			LB	UB		
Intellectual engagement	3.12 (0.84)	3.39 (0.80)	1.774	0.27	-0.03	0.56	118	0.04*
Willpower	3.40 (0.75)	3.10 (0.70)	-2.489	-0.33	-0.59	-0.06	118	0.03*
Emotional involvement	3.32 (0.71)	3.27 (0.58)	-0.513	-0.06	-0.29	0.17	118	0.23
Competency	3.42 (0.45)	3.53 (0.38)	1.433	0.11	-0.04	0.26	118	0.12
Academic performance	3.41 (0.98)	3.52 (0.75)	1.352	0.22	-0.10	0.53	110.87	0.31
Learning interest	3.33 (0.48)	3.35 (0.32)	0.781	0.02	-0.11	0.14	103.73	0.36

M: Mean score; MD: Mean difference; CI: Confidence Interval; LB: Lower Bound; UB: Upper Bound; SD: Standard Deviation.

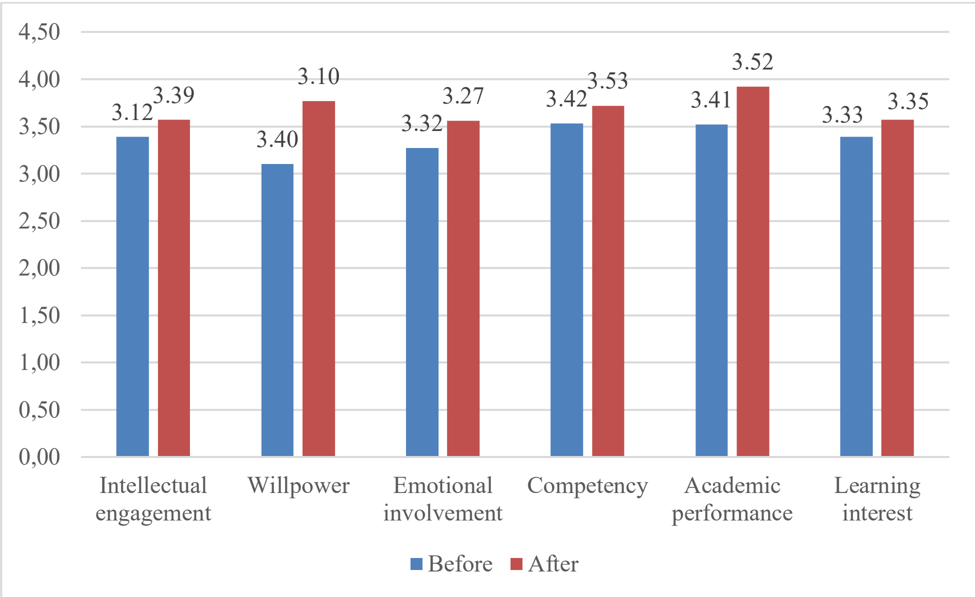

Figure 3. Mean score comparison between the control and experimental groups before the intervention

As illustrated in Figure 3, the mean scores of learning interest indicators between the control and experimental groups were closely aligned before the intervention, further supporting the absence of systematic differences. These findings establish a baseline for evaluating the impact of AR-enhanced instruction, ensuring that any post-intervention improvements can be attributed to the instructional approach rather than pre-existing disparities.

Post-intervention

Following the intervention, an independent samples t-test was conducted to compare the learning interest dimensions - including intellectual engagement, willpower, emotional involvement, competency, and academic performance - between the control and experimental groups. As presented in Table 5, statistically significant differences ($p < 0.05$) were observed across all measured variables, indicating that students in the experimental group demonstrated higher levels of learning interest than those in the control group after receiving AR-enhanced instruction.

The most substantial difference was found in academic performance, where the experimental group outperformed the control group with a mean difference of 0.75 points ($p = 0.020$). Additionally, intellectual engagement, willpower, emotional involvement, and competency all showed significant increases in the experimental group, suggesting that AR-based instruction had a positive impact on multiple aspects of student learning interest.

Table 5. Independent samples t-test after the intervention for the control and experimental groups

Dimension	M (SD)		t	MD	95% CI		*p	d	ES
	Control	Experimental			LB	UB			
Intellectual engagement	3.14 (1.05)	3.57 (0.66)	2.665	0.43	0.11	0.74	0.028	0.48	Medium
Willpower	3.43 (0.88)	3.77 (0.41)	2.733	0.34	0.94	0.59	0.035	0.50	Medium
Emotional involvement	3.27 (0.80)	3.56 (0.68)	2.042	0.27	0.01	0.54	0.011	0.39	Small
Competency	3.37 (0.78)	3.72 (0.61)	2.694	0.11	0.91	0.60	0.026	0.50	Medium
Academic performance	3.54 (1.07)	3.92 (0.80)	4.316	0.34	0.41	1.09	0.042	0.40	Small
Learning interest	3.35 (0.63)	3.71 (0.32)	4.375	0.75	0.17	0.53	0.020	0.71	Medium

M: Mean score; MD: Mean difference; CI: Confidence Interval; LB: Lower Bound; UB: Upper Bound; SD: Standard Deviation; d: Cohen's d; ES: Effect Size.

The effect sizes (Cohen's d) indicate that the AR-enhanced instruction had moderate impacts on most learning interest dimensions. Notably, *learning interest* showed the highest effect size ($d = 0.71$), suggesting a substantial motivational benefit. Dimensions such as *willpower*, *competency*, and *intellectual engagement* were moderately affected ($d \approx 0.50$), while *academic performance* and *emotional involvement* showed smaller but meaningful improvements.

As illustrated in Figure 4, the post-intervention mean scores indicate a clear distinction between the control and experimental groups, reinforcing the effectiveness of AR integration in enhancing students' engagement and academic outcomes. These findings support the argument that interactive and immersive learning environments, facilitated by AR, can contribute to a more engaging and effective learning experience in chemistry education.

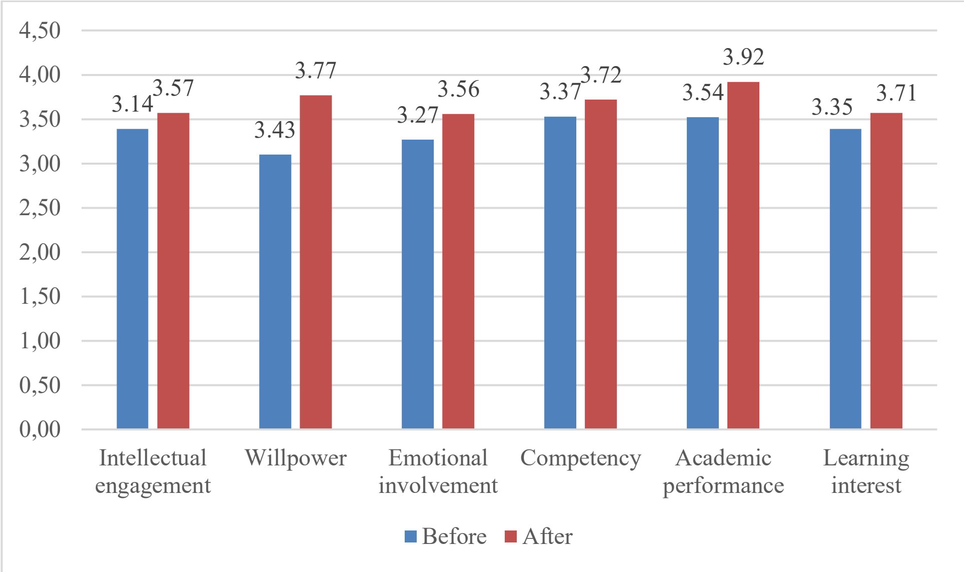

Figure 4. Mean score comparison between the control and experimental groups after the intervention

Comparison of pre- and post-intervention data within each group

A paired samples t-test was conducted to examine whether there were significant differences in learning interest, including intellectual engagement, willpower, emotional involvement, competency, and academic performance, before and after the intervention within the control and experimental groups.

For the control group

As shown in Table 6, there were no statistically significant differences ($p > 0.05$) in any measured dimensions of learning interest, indicating that the control group did not exhibit notable improvements following the intervention. The mean scores for intellectual engagement, willpower, emotional involvement, and competency remained relatively stable, suggesting that students' levels of engagement and participation in learning activities did not change significantly under traditional instruction. Similarly, academic performance, as an essential component of learning interest, showed no meaningful progress, reinforcing the limited impact of conventional teaching methods on student outcomes.

Table 6. Paired samples t-test for the control group

Dimension	M (SD)		t	Df	*p
	Before	After			
Intellectual engagement	3.12 (0.84)	3.14 (1.05)	-0.14	59	0.76
Willpower	3.40 (0.75)	3.43 (0.88)	-0.21	59	0.23
Emotional involvement	3.32 (0.71)	3.27 (0.80)	0.37	59	0.48
Competency	3.42 (0.45)	3.37 (0.78)	0.43	59	0.67
Academic performance	3.41 (0.98)	3.54 (1.07)	-1.53	59	0.95
Learning interest	3.12 (0.84)	3.14 (1.05)	-0.14	59	0.76

M: Mean score; SD: Standard Deviation.

Furthermore, Figure 5 illustrates the consistency in pre- and post-intervention mean scores, further confirming that students in the control group did not experience an increase in learning interest over time. These findings highlight the need for more interactive and immersive learning approaches, such as AR-based instruction, to effectively enhance students' engagement and learning interest in chemistry education.

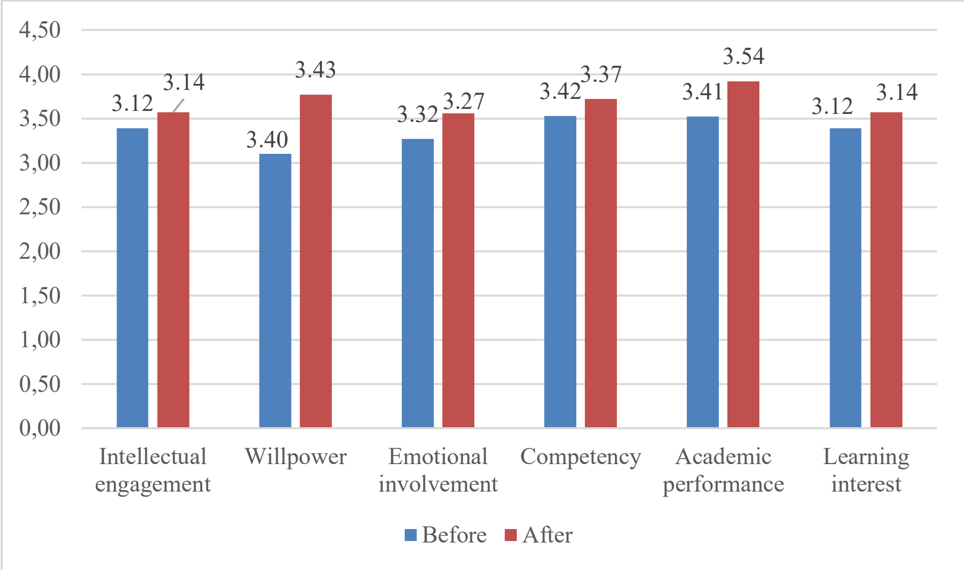

Figure 5. Mean score comparison before and after the intervention for the control group.

For the experimental group

A paired samples t-test was conducted to analyze the differences in learning interest, including intellectual engagement, willpower, emotional involvement, competency, and academic performance, before and after the intervention within the experimental group. As presented in Table 7, statistically significant differences ($p < 0.05$) were observed across all dimensions of learning interest, indicating that the AR-enhanced instructional approach had a positive impact on student engagement and performance. Specifically, willpower and academic performance showed the most substantial increases, with mean differences of 0.67 and 0.80 points, respectively, suggesting that AR-based learning fostered greater perseverance in learning activities and improved knowledge acquisition. The increases in intellectual engagement, emotional involvement, and competency further highlight the multi-faceted benefits of AR integration in chemistry education.

Table 7. Paired samples t-test for the experimental group

Dimension	M (SD)		t	Df	*p	d	ES
	Before	After					
Intellectual engagement	3.39 (0.80)	3.57 (0.66)	-1,81	59	0.02	0.25	Small
Willpower	3.10 (0.70)	3.77 (0.41)	-6,72	59	0.03	0.96	Large
Emotional involvement	3.27 (0.58)	3.56 (0.68)	-2,42	59	0.01	0.46	Medium
Competency	3.53 (0.38)	3.72 (0.61)	-2,10	59	0.01	0.37	Small-Medium
Academic performance	3.52 (0.75)	3.92 (0.80)	-6,50	59	0.04	0.52	Medium
Learning interest	3.39 (0.80)	3.57 (0.66)	-1,81	59	0.02	0.25	Small

M: Mean score; SD: Standard Deviation; d: Cohen's d; ES: Effect Sizes.

The effect sizes (Cohen's d) for within-group comparisons suggest a large impact of the AR-based intervention on students' willpower (d = 0.96), indicating strong motivational improvement. Other variables such as academic performance (d = 0.52) and emotional involvement (d = 0.46) showed moderate effects, while intellectual engagement and learning interest experienced small but positive changes.

Additionally, Figure 6 illustrates the consistent improvement across all measured variables, reinforcing those students in the experimental group exhibited enhanced learning interest after experiencing AR-based instruction. These findings provide strong empirical support for the effectiveness of AR as a pedagogical tool, demonstrating its potential to create engaging, interactive, and immersive learning experiences that contribute to higher levels of student participation and achievement in chemistry education.

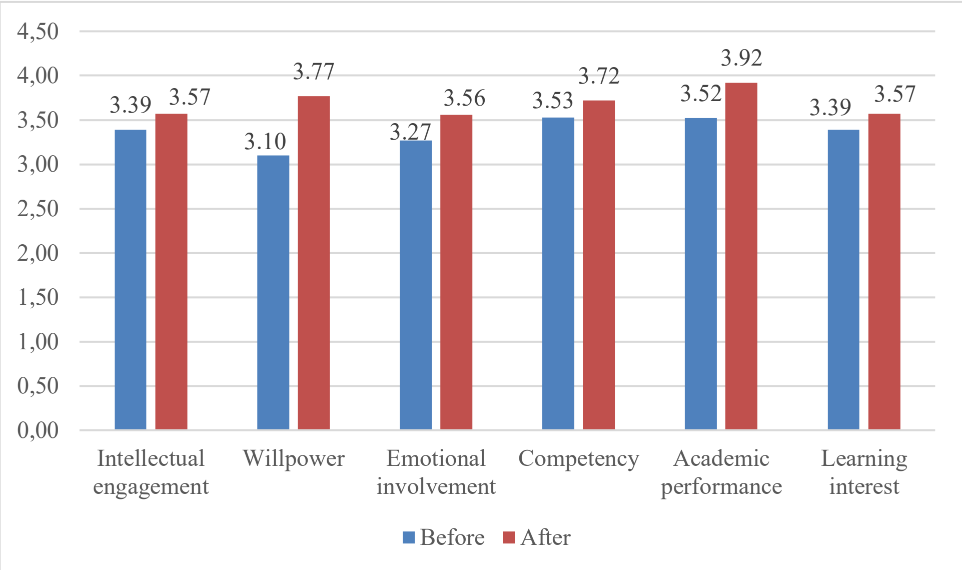

Figure 6. Mean score comparison before and after the intervention for the experimental group.

Correlation between academic performance and other learning interest dimensions

The Pearson correlation analysis results, as presented in Table 8, indicate a moderate positive correlation between academic performance and various dimensions of learning interest, including intellectual engagement, willpower, emotional involvement, and competency. The statistically significant correlations ($p < 0.05$) suggest that higher levels of learning interest are associated with improved academic performance.

Table 8. Pearson correlation analysis results

Variable	Correlation Coefficient	Sig.	Relationship Description
Academic Performance – Intellectual Engagement	0.44	0.035	Moderate Positive Correlation
Academic Performance – Willpower	0.36	0.024	Moderate Positive Correlation
Academic Performance – Emotional Involvement	0.31	0.045	Moderate Positive Correlation
Academic Performance – Competency	0.41	0.011	Moderate Positive Correlation

M: Mean score; SD: Standard Deviation.

These findings further support the impact of AR-based learning in enhancing student engagement and improving learning outcomes. The correlation between intellectual engagement and academic performance was particularly strong, reinforcing the idea that active cognitive involvement contributes significantly to academic success. Similarly, the positive correlations between willpower, emotional involvement, and competency with academic performance suggest that a well-rounded learning experience - fostering motivation, perseverance, and confidence - plays a crucial role in student achievement. These results provide additional empirical evidence for the effectiveness of AR-enhanced instruction in fostering both learning interest and academic performance, emphasizing the importance of interactive and immersive learning environments in chemistry education.

Discussion

The findings of this study demonstrate that AR-based instruction significantly enhanced students' learning interest across all measured dimensions, including intellectual engagement, willpower, emotional involvement, competency, and academic performance. The independent samples t-test results confirmed that students in the experimental group exhibited higher post-intervention mean scores than those in the control group ($p < 0.05$), indicating the effectiveness of AR integration in chemistry education. Furthermore, paired samples t-tests revealed a statistically significant improvement in learning interest within the experimental group, while no significant changes were observed in the control group. These results also reflect a moderate positive correlation between academic performance and the key dimensions of learning interest, aligning with previous studies (Pranoto & Panggabean, 2019; Thai & Nguyen, 2020; Vu et al., 2023), thereby reinforcing the positive impact of AR in chemistry education. For some studies using AR on students, it has also been shown that learning attitudes (including some aspects of learning interest such as emotional involvement and willpower) are significantly improved when using this tool (Olim et al., 2024; Elford et al., 2023). In addition, as with other studies, this study also shows that there is a correlation between aspects such as emotion and willpower and academic performance (Cai, Wang, & Chiang, 2024; Silva et al., 2023) and provides a more general overview of the correlation between academic performance and other aspects of academic interest.

However, the extent of AR's influence remains moderate, which may be attributed to several factors. The limited exposure time due to classroom constraints may have restricted students from fully exploring AR-based content. Additionally, while AR creates visually engaging effects, it can sometimes distract students from core learning objectives. Furthermore, technical issues, such as slow performance, system crashes, or device compatibility problems, were noted, particularly when students struggled to find a flat surface for AR display. These challenges suggest future research directions, including optimizing AR technology to enhance stability and compatibility across various devices and exploring pedagogical approaches that maximize the educational benefits of AR in chemistry instruction.

Although the study showed significant improvement in the experimental group after the AR-based impact, before the impact, the experimental group showed higher scores in some dimensions such as willpower and intelligence. These differences may come from the student's pre-existing characteristics that are not the primary impact of AR. For example, some students in the test group have shown a strong orientation towards science-related career paths, such as pursuing medicine, pharmacy or engineering. This career orientation may have strengthened their intrinsic motivation and involvement in Chemistry even before the intervention began. Furthermore, some of these students reported that they had prior exposure to technologyenabled learning tools, which may have contributed to their initial advantage in emotional involvement and intellectual engagement. While random assignment was not feasible in this school-based study, we were careful to ensure that both groups were comparable in terms of curriculum content, assessment conditions, and teacher experience. However, potential variables such as career aspirations or previously informal learning experience are not controlled. The post-test improvements observed in the experimental group, although significant, may partially reflect these initial differences between the groups. Future studies may benefit from stratified sampling or pairing techniques to ensure more comparable baseline profiles between groups. However, the consistent improvement model across multiple dimensions of learning interests and learning performance shows that the AR augmented approach provides authentic pedagogical value.

Conclusion

This study investigated the impact of the application of AR technology through the Delightex platform on students' interest in learning in chemistry, especially the topic of Chemical Bonding. The findings show that the application of AR in teaching has significantly improved many aspects of learning interest such as willpower, capacity, emotions and learning outcomes. Results are generally consistent with previous studies (e.g., Thai & Nguyen, 2020; Silva et al., 2023), which highlights the potential of AR in enhancing motivation, engagement, and cognitive understanding in science education. However, this study adds additional depth by using structured measurement of learning interests through multiple subdimensions, providing a more nuanced perspective on how AR affects emotional involvement outcomes. Furthermore, medium to large effect scales – especially for willpower ($d = 0.96$) – demonstrate that the intervention is not only statistically significant, but also practical.

This study contributes to some of the existing literature in a number of ways. Rigorous research design from sample selection, gender balance, and specific AR integration plans. Data analysis was conducted rigorously, beginning with the calculation of Cronbach's Alpha to assess the internal consistency of the measurement scales**.** Independent samples t-tests were employed to compare pre- and post-intervention group differences, paired samples t-tests for within-group changes, and Pearson correlation to examine the relationship between learning interest and academic performance. Statistical significance was set at $p < 0.05$, and effect sizes were reported using Cohen's d. Results were presented in detailed tables and figures to support interpretation.

Future research should focus on optimizing AR products for broader device compatibility, improving the learning experience to minimize distractions caused by technological effects, and exploring effective pedagogical strategies for integrating AR technology into chemistry teaching and learning to maximize its impact. The study also suggests expanding sample size and ensuring greater diversity in student participants, including students from both public and private schools, to provide a more comprehensive evaluation of AR's effectiveness across different educational settings. Advanced statistical methods such as regression analysis and correlation tests should be conducted to assess the degree of contribution of intellectual engagement, willpower, emotional involvement, competency, and academic performance to learning interest. Further research should also explore AR applications in other chemistry topics and instructional content, aiming to enhance students' competencies, learning motivation, and overall engagement in high school chemistry. These efforts will help solidify AR technology as an innovative tool in chemistry education while refining its application to maximize its benefits in enhancing student learning experiences.

Based on the study's findings and limitations, future research should include larger and more diverse samples to enhance generalizability. Further development of AR applications is also recommended to improve usability and reduce distractions, while educators are encouraged to integrate AR strategically to maximize its positive impact on students' learning interest.

Declarations

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Ethics Statements:
The study complied with the scientific research regulations of Ho Chi Minh City University of Education. The research proposal was approved by the University's Scientific Committee prior to data collection. Participants were fully informed about the study, joined voluntarily, retained the right to withdraw at any time, and were assured of anonymity.

Conflict of Interest:
The authors declare no competing interest.

Informed Consent:

Data availability:
Data supporting the findings and conclusions are available upon request from the corresponding author.

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