JPPIPA 11(12) (2025)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Implementation of the SCCrT–Augmented Reality Model to Improve Students' Critical and Creative Thinking Skills and Science Literacy in Chemical Bonding Concepts

Rusmansyah[1*], Parham Saadi[1], Hestu Anggrah[1], Ade Rahmawati Idris[1], Gusti Aulia Nasution[1], Puput Riadi[1], Vermiana Nur Utami[1]

[1] Chemistry Education, Faculty of Teacher Training and Education, Lambung Mangkurat University, Banjarmasin, Indonesia.

Received: October 09, 2025
Revised: November 13, 2025
Accepted: December 25, 2025
Published: December 31, 2025

Corresponding Author:
Rusmansyah
rusmansyah@ulm.ac.id

DOI: 10.29303/jppipa.v11i12.13085

Abstract: The low level of science literacy and higher-order thinking skills among Indonesian students, as indicated by PISA results, necessitates more interactive and contextual learning innovations. This study aimed to examine the effectiveness of the SCCrT model assisted by Augmented Reality (AR) in improving students' critical thinking, creative thinking, and science literacy in chemical bonding topics. This study used a quasi-experimental design with a nonequivalent control group design involving 11th-grade students at SMAN 1 Alalak and SMAN 12 Banjarmasin. The research instruments consisted of critical thinking, creative thinking, and science literacy tests. The results showed that the experimental groups achieved higher average post-test scores than the control groups across all variables. In critical thinking, the scores were higher in the experimental classes (82.85 and 83.56) than in the control classes (75.00 and 74.00). Creative thinking scores were higher in the experimental classes (81.54 and 82.4) than in the control classes (73.85 and 72.72). Similarly, scientific literacy scores were higher in the experimental classes (81.79 and 83.71) than in the control classes (74.47 and 73.44). Independent sample *t*-tests indicated significant differences between the experimental and control groups ($p < 0.05$) with Cohen's *d* values exceeding 0.78, indicating a substantial effect. Student observations and responses also revealed positive engagement during SCCrT–AR learning activities. In conclusion, the AR-assisted SCCrT model is effective in enhancing students' critical and creative thinking, as well as their science literacy, and represents a promising alternative for chemistry learning in the digital era.

Keywords: Augmented reality; Chemical bonding; Critical-creative thinking; SCCrT; Science literacy

Introduction

Education is a critical aspect of improving the quality of human resources (HR) and the competitiveness of a nation. In the modern era, characterized by rapid technological development, education plays a crucial role in preparing the younger generation to face global challenges (Bareke et al., 2021). A well-developed and excellent education system is crucial for cultivating high-quality human resources among the millennial generation, particularly in terms of the quality of education and its relevance to societal demands and workplace needs. In the context of the Digital Society 5.0 era, education equips the younger generation with critical thinking, creativity, and emotional intelligence, enabling them to adapt to rapid

How to Cite:
Rusmansyah, Saadi, P., Anggrah, H., Idris, A. R., Nasution, G. A., Riadi, P., & Utami, V. N. (2025). Implementation of the SCCrT–Augmented Reality Model to Improve Students' Critical and Creative Thinking Skills and Science Literacy in Chemical Bonding Concepts. *Jurnal Penelitian Pendidikan IPA*, *11*(12). https://doi.org/10.29303/jppipa.v11i12.13085

technological advances and global competition. Thus, education is crucial in enhancing a nation's competitiveness in the modern era (Abdillah et al., 2022). Education significantly enhances the quality of human resources, which is crucial for a nation's advancement. Effective human resource management in education focuses on developing competencies, thereby enhancing the overall quality of education and fostering competitiveness in the global landscape (Tiara et al., 2023).

Education is essential for preparing students to compete and adapt in the future, in an era of ever-evolving technology. The 21st century demands improved digital literacy and competence. As a result, educational curricula must be adapted (Meyanti & Lasmawan, 2023). One of the main focuses is the development of critical thinking, creativity, and science literacy skills, which are key to success on the international stage (González-pérez & Ramírez-montoya, 2022). The results of a 2018 study by the Programme for International Student Assessment (PISA) ranked Indonesia 70th out of 78 countries in science, indicating that Indonesian students' science literacy skills are still low. This literacy includes critical thinking skills, namely the ability to distinguish between valid and invalid arguments, as well as understanding basic concepts and methods in science (Atmojo et al., 2022; Dianti et al., 2023; Karataş et al., 2022). Empirical evidence shows that improvements in scientific literacy are closely associated with the development of students' critical thinking skills, as both competencies are shaped by instructional strategies used in science classrooms (Susilawati et al., 2025). Additionally, PISA 2022 assessed the creative thinking skills of students from 64 countries worldwide. The creative thinking skills of students in Indonesia indicate that only 31% of Indonesian students have achieved a basic level of creative thinking, which is significantly lower than the OECD average of 78%. Some of the survey results provide evidence that science literacy and critical and creative thinking skills among students in Indonesia are still low (Aiman et al., 2020; Aufa et al., 2021). Many still complain about the low critical and creative thinking skills of graduates from elementary school to university in Indonesia (Sujanem & Putu Suwindra, 2023).

Education in Indonesia will be more advanced if it focuses on developing critical thinking skills and science literacy, which are urgently needed in the era of an industrialized economy era (Khery et al., 2020; Uslan et al., 2024). Well-designed science learning that actively engages students in reasoning and contextual problem-solving has been shown to empower both critical thinking skills and scientific literacy simultaneously (Bramastia et al., 2025). High-quality education must prepare students not only to master subject content but also to develop important life skills such as innovation, adaptability, and critical thinking (Huda et al., 2025). Critical thinking-based learning increases learning efficiency by training students to be more communicative, collaborative, creative, innovative, and able to solve real-world problems (Febriani & Suryani, 2022; Zekri et al., 2020). There are four leading indicators of critical thinking, namely analysis, inference, evaluation, and decision making (Prayogi et al., 2024). Critical thinking skills can be implemented through the learning process. Students who can think critically well will also develop creative mindsets (Suwistika et al., 2024). Creative thinking skills in the 21st century are not only about creative ways of thinking, such as originality, flexibility, and fluency (Mardiyah et al., 2021; Rahmawati et al., 2023). Meanwhile, creative thinking enables students to view problems from multiple perspectives, allowing them to produce new and innovative solutions (Saeed & Ramdane, 2022). Low critical thinking, creative thinking, and science literacy skills in Indonesian education have the potential to hamper the nation's progress and competitiveness in facing global challenges (Pujawan et al., 2022).

The definition of science literacy, according to the OECD (2003), is the ability to use scientific knowledge, identify questions or problems, and draw conclusions based on data or evidence (Bahtiar et al., 2022; Mahmudah et al., 2020). Science literacy is the understanding or knowledge of scientific concepts and processes that individuals need, especially when making decisions and contributing to social and economic aspects, with problem-solving skills (Dewi et al., 2021; Mm et al., 2020; Prasetia & Adlan, 2022; Spitzer & Fraser, 2020). Science literacy skills are basic competencies that students must have in the field of science, and have been recognized as an important issue that is currently being discussed by all countries, including Indonesia (Falantin & Qosyim, 2021). Students who lack the skills to analyze information and understand scientific principles critically will find it challenging to make the right decisions and keep up with the latest technological developments (Leasa et al., 2021).

The existence of various forms of information in various media today requires students to have the skills to respond, think critically and creatively, and have sufficient knowledge that can be mastered through students' scientific literacy skills (Heliawati et al., 2022). One of the solutions offered is the SCCrT (Science Critical Creative Thinking) model. The SCCrT model is a constructivist model that involves students in the process of understanding concepts and applying them in experimental activities as a form of proving the truth of the concepts learned to train critical and creative thinking skills (Dwi et al., 2023). The steps of the SCCrT learning model are 1) student orientation; 2) scientific activities involving critical and creative thinking; 3) presentation of scientific activity results; 4) completion of critical and creative thinking tasks; and 5) evaluation and reflection (Rusmansyah et al., 2022).

Through these stages, the SCCrT model actively encourages students to construct knowledge, apply scientific reasoning, and reflect on their learning processes. Empirical studies have reported that SCCrT tends to be more effective than conventional instruction in improving students' critical and creative thinking skills in chemistry learning. Therefore, the characteristics of the SCCrT model align closely with the need to address low higher-order thinking skills and science literacy, as reported in international assessments such as PISA (Huda et al., 2022; Mazzuco et al., 2022).

Chemistry learning involves abstract concepts that require students to understand microscopic and symbolic representations. These abstract characteristics often make chemistry difficult to comprehend through conventional instructional methods. The science learning process should ideally begin with the development of a systematic thinking framework, including problem formulation, hypothesis development, solution seeking, theory review, and conclusion drawing (Rios et al., 2020; Sutanto et al., 2022). One of the fundamental concepts in high school chemistry (grade 11) is chemical bonding, which explains the forces that bind atoms together to form molecules or chemical compounds. The subject of chemical bonding can be challenging to understand due to the complexity of the differences between ionic, covalent, metallic, and hydrogen bonds. The solution is to utilize 3D visualization and Augmented Reality (AR) to enable students to visualize molecular structures interactively (Mazzuco et al., 2022).

AR combines the real world with virtual objects, making it easier to understand abstract concepts in chemistry (Hidayat & Wardat, 2024). AR provides interactive three-dimensional visualizations that allow students to observe and manipulate virtual representations of chemical structures within real-world contexts. Systematic reviews have consistently reported that AR supports conceptual understanding, enhances spatial reasoning, and improves students' engagement and motivation in chemistry education. Consequently, AR is considered a relevant technological tool to reduce abstraction and support meaningful learning in chemistry classrooms (Ajit et al., 2020; Garzón, 2021). The combination of the SCCrT model with AR technology has the potential to enhance students' critical thinking, creativity, and science literacy skills (Garzón, 2021).

Although previous studies have examined the effectiveness of constructivist learning models and augmented reality separately, limited research has integrated the SCCrT model with AR technology to simultaneously enhance critical thinking, creative thinking, and science literacy within a single instructional framework. In addition, most AR-based chemistry studies primarily focus on conceptual understanding or motivation, rather than higher-order cognitive competencies. Therefore, this study was conducted to examine the effectiveness of the AR-assisted SCCrT model in improving students' critical thinking, creative thinking, and science literacy in chemical bonding materials, thereby offering a novel contribution by integrating the SCCrT pedagogical model with Augmented Reality to address multiple higher-order learning outcomes simultaneously (Pujawan et al., 2022).

Method

This study employed a quasi-experimental design using a nonequivalent Control Group Design. The participants were eleventh-grade students from two public senior high schools (SMAN 1 Alalak and SMAN 12 Banjarmasin), with one class assigned as the experimental group and one class as the control group at each school. The experimental group was taught using the Science Critical Creative Thinking (SCCrT) model assisted by Augmented Reality (AR), while the control group received conventional chemistry instruction (Miller et al., 2020). Both groups were administered pretests and posttests. The research flow is shown in Figure 1.

The independent variable of this study was the implementation of the SCCrT–AR learning model. The dependent variables included students' critical thinking skills, creative thinking skills, and science literacy. Data were collected using tests designed to measure each of these variables, which were administered before and after the instructional intervention. The instruments were developed based on relevant indicators and validated prior to use.

The research procedure consisted of determining the experimental and control groups, administering pretests, implementing the instructional treatments, and administering posttests. Quantitative data were analyzed by comparing pretest and posttest scores to examine learning improvements and by conducting independent sample t-tests to identify differences between the experimental and control groups (Abraham & Supriyati, 2022). Qualitative data were obtained from classroom observations and student response questionnaires to support the quantitative findings.

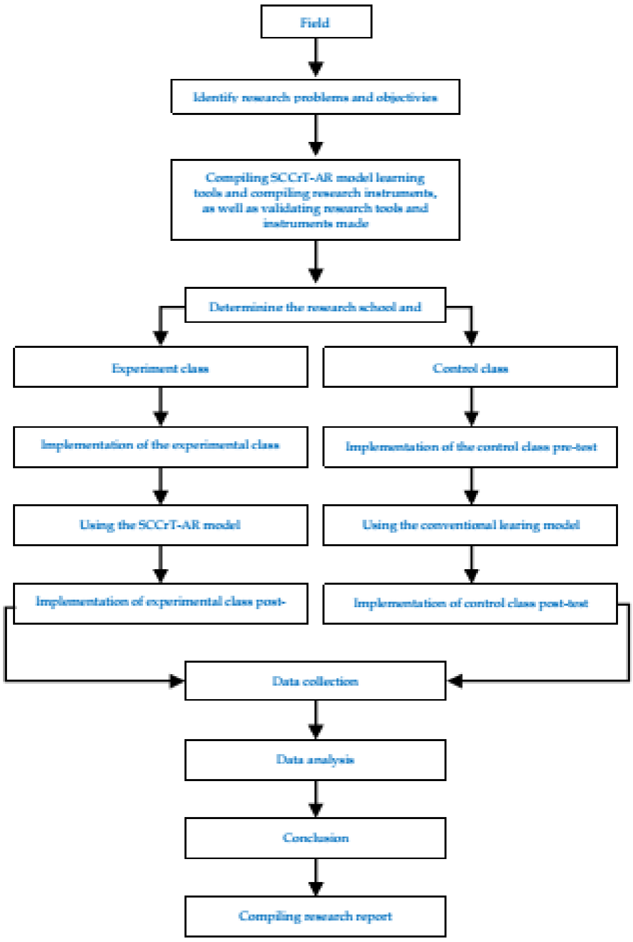

Figure 1. Research flow

Result and Discussion

The results of the study indicate that the application of the SCCrT model assisted by Augmented Reality (AR) can significantly improve students' critical thinking, creative thinking, and science literacy skills. These findings align with the research hypothesis that the use of a constructivist approach, combined with interactive visual technology, can enhance the understanding of abstract chemistry concepts.

Analysis Distribution

As presented in Table 1, the experimental class showed a higher average gain in critical thinking compared to the control class in both schools. At SMAN 1 Alalak, the experimental class reached 30.08, while the control class only reached 15.31. A similar pattern was also observed at SMAN 12 Banjarmasin, with a score of 29.62 in the experimental class and 14.71 in the control class. The results of the t-test, with $p < 0.001$ and a Cohen's d effect size exceeding 0.5, indicate a significant and powerful influence. This finding is in line with a study previously conducted by Allo et al., (2022) which proved that scientific activity stages in the SCCrT model, such as problem formulation and empirical analysis, effectively stimulate students' critical thinking ability to identify, differentiate, and deeply evaluate arguments.

Table 1. Pre-test and Post-test Results for Critical Aspects

School	Class	Pre-test	Post-test
SMAN 1 Alalak	Control	19.90	75.00
	Experiment	20.65	82.85
SMAN 12 Banjarmasin	Control	20.88	74.00
	Experiment	20.21	83.56

The results of creative thinking skills, as presented in Table 2, also showed significant improvement. The experimental class yields an average gain of more than 31, whereas the control class averages around 16. The p-value < 0.001 and the effect size of more than 0.7 strengthen the evidence that SCCrT–AR learning is very effective in generating innovative ideas and solutions. According to the study by Kurniawan et al. (2024), the visualization of molecules using Augmented Reality (AR) technology enables students to view the structure from various angles, thereby facilitating the emergence of new, varied, and original ideas.

Table 2. Pre-test and Post-test Results for Creative Aspects

School	Class	Pre-test	Post-test
SMAN 1 Alalak	Control	20.08	73.85
	Experiment	19.24	81.54
SMAN 12 Banjarmasin	Control	20.79	72.72
	Experiment	20.23	82.46

Overall, improvements in the three aspects of critical thinking, creative thinking, and scientific literacy indicate that the application of the SCCrT model, assisted by Augmented Reality, can enhance the quality of chemistry learning. This model helps students understand abstract concepts, reason scientifically, and relate knowledge to real phenomena, thus positively impacting the development of higher-order thinking skills. This is in line with research Wulandari et al., (2020) that interactive molecular visualization through AR helps students view structures from various perspectives, thereby encouraging the emergence of new, more varied, and original ideas.

Table 3. Pre-test and Post-test Results for Science Literacy Aspects

School	Class	Pre-test	Post-test
SMAN 1 Alalak	Control	19.00	74.47
	Experiment	19.94	81.79
SMAN 12 Banjarmasin	Control	17.24	73.44
	Experiment	17.79	83.71

Overall, the descriptive analysis results in Table 3 indicate that students' science literacy improved in both schools, across both experimental and control classes. However, the increase in the experimental class tended to be higher than in the control class. This is in line with research by Mazzuco et al. (2022) that indicates the application of the Augmented Reality-assisted SCCrT model is more effective in helping students understand abstract concepts of chemical bonds and relate them to real phenomena, thereby having a positive impact on improving their science literacy.

Table 4. Paired t-Test Results (Pre-test and Post-test)

School	Class	Aspect	Mean Pre	Mean Post	p
SMAN 1 Alalak	Experiment	Critical	20.65	82.85	0.00
	Experiment	Creative	19.24	81.54	0.00
	Experiment	Science Literacy	19.94	81.79	0.00
	Control	Critical	19.90	75.00	0.00
	Control	Creative	20.08	73.85	0.00
	Control	Science Literacy	19.00	74.47	0.00
SMAN 12 Banjarmasin	Experiment	Critical	20.21	83.56	0.00
	Experiment	Creative	20.23	82.46	0.00
	Experiment	Science Literacy	17.79	83.71	0.00
	Control	Critical	20.88	74.00	0.00
	Control	Creative	20.79	72.72	0.00
	Control	Science Literacy	17.24	73.44	0.00

The t-test results in Table 4 show a significant difference between the experimental classes and the control classes on all three aspects in both schools ($p < 0.001$). The average post-test score of the experimental class was more consistent and higher compared to the control class.

Table 5. Results of the Unpaired T-test (Post-test Experiment vs Control)

School	Aspect	Mean Experiment	Mean Control	p
SMAN 1 Alalak	Critical	82.85	75.00	0.00
	Creative	81.54	73.85	0.00
	Science Literacy	81.79	74.47	0.00
SMAN 12 Banjarmasin	Critical	83.56	74.00	0.00
	Creative	82.46	72.72	0.00
	Science Literacy	83.71	73.44	0.00

Based on Table 5 above, at SMAN 1 Alalak, the average scores for critical thinking increased from 75.00 to 82.85, creative thinking from 73.85 to 81.54, and science literacy from 74.47 to 81.79. This shows that the SCCrT model, assisted by Augmented Reality (AR), effectively enhances higher-order thinking ability, primarily through stages that demand scientific analysis and empirical proof.

Similar results were also found at SMAN 12 Banjarmasin, where the average experimental class score was higher in all aspects: critical thinking (83.56 vs. 74.00), creative thinking (82.46 vs. 72.72), and science literacy (83.71 vs. 73.44). A very small p-value ($p < 0.001$) indicates a significant difference, confirming that the implementation of SCCrT–AR has a positive impact on the ability to think critically, creatively, and scientifically literate among students.

While the p-value confirms the existence of statistically significant differences between groups, the large effect size (Cohen's $d > 0.5$) provides stronger evidence of the practical effectiveness of the SCCrT–AR model (Cohen, 1988). A large effect size indicates that the observed differences are not only statistically detectable but also educationally meaningful. This finding suggests that the SCCrT–AR intervention contributes substantially to students' learning outcomes, rather than producing trivial gains, which is particularly important in educational research where practical relevance is as critical as statistical significance.

In general, these results reinforce the findings of the descriptive analysis previously presented. The SCCrT–AR model has been proven to contribute significantly to improving higher-order thinking skills (HOTS), as it integrates scientific processes with interactive visual learning.

Observation of Student Activities and Responses

In addition to the test results, observations of learning activities revealed that the level of student engagement in the experimental class reached an average of 4.41–4.43 on a 5-point Likert scale (excellent category), surpassing that of the control class, which averaged 3.12–3.25. Student responses, as indicated through questionnaires, also showed a very positive perception of SCCrT–AR-based learning, with an average score of above 3.5 on a scale of 4. This confirms that students feel more motivated, interested, and better equipped to understand the material through the use of AR, which may contribute to the observed improvements in learning outcomes.

Overall, these findings suggest that the SCCrT–AR model is not only effective in enhancing cognitive outcomes (critical thinking, creativity, literacy) but also in improving affective aspects, such as motivation and positive attitudes toward learning. These results are consistent with constructivist theory and previous research by Fredricks et al., (2004) and Garzón, (2021a), which emphasize the importance of active student engagement through scientific activities and the use of digital technology in science education.

The implementation of the Augmented Reality-assisted SCCrT model can be an innovative alternative in chemistry learning, especially for abstract concepts such as chemical bonds, while also serving as a solution to improve students' science literacy and higher-order thinking skills in the digital age.

Conclusion

The study's results show that the application of the SCCrT model, aided by Augmented Reality (AR), consistently improves students' critical thinking, creative thinking, and science literacy skills significantly compared to conventional learning methods. The results showed that the experimental groups achieved higher average post-test scores than the control groups across all variables. In critical thinking, the scores were higher in the experimental classes (82.85 and 83.56) than in the control classes (75.00 and 74.00). Creative thinking scores were higher in the experimental classes (81.54 and 82.4) than in the control classes (73.85 and 72.72). Similarly, scientific literacy scores were higher in the experimental classes (81.79 and 83.71) than in the control classes (74.47 and 73.44). Independent sample t-tests indicated significant differences between the experimental and control groups ($p < 0.05$) with Cohen's d values exceeding 0.78, indicating a substantial effect. In addition, observations of student activities and response questionnaires also revealed active engagement and positive attitudes towards learning, leading to the conclusion that the SCCrT–AR model is not only effective in improving cognitive abilities but also in enhancing student motivation and learning experiences. Thus, this model is worthy of being used as an innovative alternative in chemistry learning, particularly for abstract concepts such as chemical bonds, to enhance the quality of science education in the digital age.

Acknowledgments
We would like to express our gratitude to the Rector of ULM who has provided research funds, LPPM ULM who issued the research permit, the South Kalimantan Provincial Education Office who has granted the research permit, the Principal of SMAN 12 Banjarmasin and the Principal of SMAN 1 Alalak, the Chemistry Teachers of SMAN 12 Banjarmasin and the Chemistry Teachers of SMAN 1 Alalak, as well as the Students of SMAN 12 and SMAN 1 Alalak, who granted permission to carry out research activities and the chemistry students involved in this research, so that the research can be carried out smoothly.

Author Contributions
All authors contributed to writing this article.

Funding
No external funding.

Conflicts of Interest
No conflict interest.

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