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The Impact of Augmented Reality Integrated Mobile Learning on High School Students' Creative Thinking Skills in Chemistry

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Abstract

The aim of this study was to examine the Augmented Reality (AR) Integrated Mobile Learning for enhancing creative thinking skills in high school chemistry students. The research employed an experimental method, utilizing creative thinking tests as the data collection instrument. Both control and experimental groups were involved, comprising a total of 72 upper secondary school students studying chemistry. Data analysis included normality and homogeneity tests. The findings indicated a significant improvement in students' creative thinking abilities. A conceptual model was developed, demonstrating that AR-integrated mobile learning could enhance creative thinking through several key factors: media characteristics, learning management, pedagogical principles, and technical aspects of the media. The study recommends incorporating technology skills from teachers, students, and available resources, which could potentially yield different outcomes. These findings imply that educational policymakers and curriculum developers should consider integrating AR-based mobile learning platforms into national chemistry curricula to systematically foster students' creative thinking skills in alignment with 21st-century learning demands.

Keywords: creative thinking, mobile learning, augmented reality, chemistry, conceptual model

Introduction

Creative thinking skills are a core aspect of 21st-century learning, emphasized at all educational levels in Indonesia (Saptenno et al., 2019; Yayuk et al., 2020; Nurdiana et al., 2020). Chemistry is one of the subjects that fosters these skills.

The current Indonesian curriculum, known as the 2013 Curriculum, emphasizes scientific inquiry and the nature of science (Sulistina et al., 2021), making Chemistry a suitable subject to cultivate creative thinking skills. The Indonesian education system has recently transitioned from the 2013 Curriculum to the Merdeka Curriculum, which was officially implemented in 2022. The Merdeka Curriculum emphasizes student-centered learning, creativity, critical thinking, and the development of the Pancasila Student Profile (Profil Pelajar Pancasila), thereby increasing the relevance of Chemistry for cultivating creative thinking skills (Hunaepi & Suharta, 2024; Rizaldi & Fatimah, 2023). This study was conducted during the transitional period between these curricula; nevertheless, fostering creative thinking skills remains a central objective in both frameworks. However, challenges arise in practice. Students often perceive Chemistry as abstract and submicroscopic, leading to misconceptions about the subject matter. Fostering creative thinking skills in chemistry education necessitates instructional strategies that bridge the gap between abstract concepts and concrete experiences. Chemistry is defined by three levels of representation: macroscopic, submicroscopic, and symbolic, which students often find challenging to integrate (Jegstad, 2024). According to de Quadros et al. (2011), one of the biggest challenges in Chemistry education lies in how concepts are introduced. These concepts should allow students to engage deeply with Chemistry rather than merely memorize definitions or formulas. Ideally, students should gradually adopt these concepts as part of their thinking process. Consequently, teachers face persistent difficulties in designing instructional approaches that stimulate creative thinking in Chemistry. Moreover, previous research by Sugiyanto et al. (2018) revealed that students' creative thinking skills, particularly in problem-solving, were unsatisfactory. This is further confirmed by the PISA 2022 results, which confirm that Indonesian students performed below the international average in creative thinking compared to other participating countries, highlighting the urgent need for targeted instructional interventions (OECD, 2023).

Creative thinking is a cognitive process that involves mental phenomena such as memory, categorization, and manipulation of objects (Ritter et al., 2020). This ability is not innate but can be developed through instruction (Kienitz et al., 2014; Ritter & Mostert, 2017). Despite this, current learning practices often emphasize rote memorization over cognitive strategy instruction (Ritter & Mostert, 2017). Numerous studies have explored methods to improve students' creative thinking and problem-solving abilities through various innovative learning models (Hung et al., 2008). Research has also shown a link between creative thinking and academic performance (Anwar et al., 2012; Gralewski & Karwowski, 2012; Akpur, 2020), despite the long-standing nature of this theme in the psychology of creativity (Getzels & Jackson, 1962; Cicirelli, 1965). To enhance creative thinking, teachers are encouraged to explore students' interests and design tasks or activities that promote imagination and reflective thinking (Zygmunt & Schaefer, 2006). In this context, the integration of technology-based learning media represents a promising instructional strategy. Studies indicate that students' creative thinking abilities are significantly affected by the chosen learning model and media, with teacher-centered and conventional methods identified as primary inhibiting factors (Wannapiroon & Pimdee, 2022). Additionally, Chan (2012; 2013) highlights that art can be used to nurture creative thinking by encouraging students to think outside the box.

Although technology-enhanced learning has attracted considerable attention, there is a notable gap in the literature regarding the integration of mobile learning and augmented reality (AR) to foster creative thinking skills in secondary school Chemistry. Previous research has examined AR in science and Chemistry education (Ripsam & Nerdel, 2022; Nguyen, 2024), but the primary focus has been on conceptual understanding, spatial reasoning, and motivation, with limited emphasis on creative thinking as a measurable outcome. In addition, research that investigates AR and mobile learning as an integrated instructional model, rather than as a supplementary tool, remains limited. Various forms of media can be used to stimulate creative

thinking, aligning with advancements in technology. For instance, Busquet & Vinken (2019) employed social media to enhance creative thinking, while Berestova et al. (2021) utilized social networks, even with digital game media for early childhood (Xiong et al., 2022). Other forms of media, such as artificial intelligence, have also been explored (Fan & Zhong, 2022). A systematic literature review of augmented reality (AR) applications in senior high school education identified a growing adoption of AR to enhance key Education 4.0 competencies, such as creative thinking, critical thinking, communication, and collaboration (Hanggara et al., 2024).

These studies demonstrate that learning media can effectively cultivate creative thinking, leading to the development of the Augmented Reality Integrated Mobile Learning Model. Mobile learning integrated with augmented reality (AR) combines these technologies in a single smartphone platform to train students' creative thinking. Mobile learning leverages mobile devices to access email, messaging services, MLNFS-AR content, and computer applications, expanding the usability of these devices. AR, which integrates virtual elements like text, animation, and 3D models into the real world, can operate on mobile devices such as smartphones and tablets. This technology facilitates the understanding of subjects requiring 3D visualization.

AR has garnered attention in education due to its potential to enhance learning and teaching, particularly in Chemistry (Dawley & Dede, 2014). Previous studies have investigated the use of AR in Chemistry education (Iordache et al., 2012; Cai et al., 2014; Chang & Chung, 2018). Recent bibliometric analyses indicate an annual growth rate of 17.58% in augmented reality (AR)-related publications in chemistry education from 2002 to 2023, demonstrating the increasing recognition of AR as a transformative pedagogical tool (Nguyen, 2024). AR applications have been shown to improve spatial reasoning, facilitate visualization of molecular geometries and chemical reactions, and increase student engagement with abstract content (Ripsam & Nerdel, 2024). Chemistry is often perceived as difficult due to its abstract nature, symbolic representations, and the need for spatial reasoning (Holstermann et al., 2010). AR, which merges virtual simulations with the physical world, can help students grasp these abstract concepts more effectively (Belford & Moore, 2016). Simplifying these concepts enhances students' interest and engagement (Swarat et al., 2012), which can also nurture their creative thinking skills.

Treffinger et al. (2002) provide four indicators of creative thinking, fluency, flexibility, originality, and elaboration, aligned with teacher guidelines for instruction. Fluency refers to the ability to generate a large number of ideas in response to open-ended questions. Flexibility involves examining ideas from multiple perspectives. Originality is the ability to generate novel ideas, while elaboration refers to expanding on and adding details to ideas. These four indicators serve as benchmarks for students' creative thinking in Chemistry. This study introduces a conceptual model that integrates augmented reality (AR)-based mobile learning with pedagogically grounded principles, specifically addressing the four indicators of creative thinking within high school Chemistry. In contrast to previous research that utilized AR primarily as a supplementary visualization tool, the present study positions AR-integrated mobile learning as a comprehensive instructional model. This distinction offers both a new theoretical and practical framework to the existing literature. Thus, this study reviews the Augmented Reality Integrated Mobile Learning Model for training creative thinking skills in Chemistry for high school students.

Method

Jenis penelitian yang dilakukan adalah penelitian kualitatif dengan subjek penelitian adalah peserta didik kelas X-E2 SMA Negeri 36 Jakarta yang berjumlah 36 orang. Menurut

Creswell (2018), penelitian kualitatif bertujuan untuk memahami fenomena sosial dari perspektif partisipan, sehingga data yang diperoleh dapat memberikan wawasan yang le

Results and Discussion

Research Design

This research examines the development and evaluation of Augmented Reality (AR)-integrated mobile learning media as an innovative instructional tool designed to enhance students' creative thinking skills in Chemistry, with a specific focus on Salt Hydrolysis. The study was implemented within the Merdeka Curriculum framework, which prioritizes student-centered learning and the cultivation of higher-order thinking skills, including creativity (Hunaepi & Suharta, 2024). This study employed an experimental research method using a pretest-posttest control group design. In this design, two groups were randomly selected and subjected to a pretest to assess their initial condition. Based on the pretest results, the experimental group received instruction through integrated mobile learning augmented reality, while the control group utilized PowerPoint media for learning activities on salt hydrolysis. After the intervention, both groups were given a posttest.

The implementation of this design addresses the identified research gap, which is the limited availability of empirically tested augmented reality (AR)-based mobile learning media specifically targeting the four indicators of creative thinking fluency, flexibility, originality, and elaboration in high school Chemistry education. By comparing AR-integrated media with conventional PowerPoint-based instruction, the study demonstrates the novelty and effectiveness of the developed media within a controlled experimental setting.

Table 1. Research Design

Group	Treatment	Pre-test	Post-test
Control	PowerPoint Media	Creative thinking test	Creative thinking test
Experiment	Augmented Reality Integrated Mobile Learning	Creative thinking test	Creative thinking test

Sample and Data Collection

The study was conducted at State High School 54 Jakarta, Indonesia, with the research sample comprising students from class XI MIPA 3 and XI MIPA 4. Both classes were studying Chemistry under the Merdeka Curriculum at the time of the study. Class XI MIPA 4 served as the experimental group, and class XI MIPA 3 acted as the control group, with each class consisting of 36 students. Data collection was carried out using a creative thinking test related to salt hydrolysis in chemistry learning. This test aimed to evaluate students' creative thinking skills, utilizing open-ended questions assessed according to the indicators of fluency, flexibility, originality, and elaboration. The pretest was administered before the salt hydrolysis material was taught, and the posttest followed upon completion of the learning process. A total of 19 questions were used, covering the four indicators of creative thinking skills.

Data Analysis

Prior to hypothesis testing, statistical assumption checks were conducted to ensure the validity of the analysis. The results of the Kolmogorov-Smirnov normality test indicated that the p-value was greater than 0.05, suggesting that the data followed a normal distribution. Additionally, the Levene homogeneity test produced a p-value greater than 0.05, confirming the homogeneity of variance across groups. Since both assumptions were met, an Independent-Sample T-Test was employed to compare the post-test scores between the experimental and

control groups, while a paired t-test was used to examine changes between pre-test and post-test scores within each group, at a significance level of 0.05

Results and Discussion

Pre-test and Post-test Results of Experimental and Control Groups

The results of the pre-test data analysis for both the experimental and control groups are presented in Table 2.

Table 2. Pre-test Results of Experimental Class and Control Class

Data	Group	
	Experimental	Control
Max	38	43
Min	22	24
Mean	31.72	29.33
Median	32	28
Number of Students	36	36

According to Table 2, the average score of class XI MIPA 4 (31.72) is nearly the same as the average score of class XI MIPA 3 (29.33), indicating that the initial creative thinking abilities of students in these two groups are comparable. The post-test data analysis for the experimental and control groups can be found in Table 3.

Table 3. Post-test Results of Experimental Class and Control Class

Data	Group	
	Experimental	Control
Max	97	85
Min	65	50
Mean	77.47	72.44
Median	78	74
Number of Students	36	36

As shown in Table 3, the experimental group's average score was 77.47, whereas the control group achieved an average of 72.44. The higher average score of the experimental group suggests a difference in creative thinking abilities between the two groups. A t-test was conducted to determine the significance of the changes in pre-test and post-test scores for both the control and experimental groups. The t-test was deemed appropriate as the sample data were normally distributed and exhibited homogeneous variances. The analysis utilized the Independent-Sample T-Test, performed through SPSS 25.0 software, to examine whether mobile learning integrated with augmented reality had an impact on students' creative thinking abilities regarding salt hydrolysis in the experimental group as compared to the control group.

Table 4. Experimental Class

	M	N	SD	Std. Error Mean	t	p
Pre-test	31.722	36	4.240	0.706	-35.381	0.000
Post-test	77.472	36	7.048	1.174		

Based on the descriptive statistics for the Pre-Test and Post-Test results, the experimental group's Pre-Test average was 31.722, while the Post-Test average increased to 77.472. The sample size consisted of 36 students, with a Pre-Test standard deviation of 4.240 and a Post-Test standard deviation of 7.048. The standard error mean for the Pre-Test was 0.707, and for the Post-Test, it was 1.175.

Since the average Pre-Test score (31.722) is less than the Post-Test score (77.472), there is a clear descriptive difference between the two sets of results. To determine whether this difference is statistically significant, a paired sample t-test was conducted. Based on the output from the Paired Samples Test, the Sig. (2-tailed) value was 0.000, which is less than 0.05. Therefore, H₀ is rejected, and H₁ is accepted, leading to the conclusion that mobile learning integrated with augmented reality positively impacts students' creative thinking abilities.

a. Control Class

	Mean	N	SD	Std. Error Mean	t	p
Pretest	29.333	36	4.962	0.827	-26.433	0.000
Posttest	72.444	36	7.758	1.293		

Based on the descriptive statistical results from both samples in the research data, namely the Pre-Test and Post-Test, the Pre-Test yielded a mean score of 29.333, while the Post-Test produced a mean score of 72.444. The study involved 36 student respondents, with a standard deviation of 4.963 for the Pre-Test and 7.759 for the Post-Test. The standard error of the mean for the Pre-Test was 0.827, and for the Post-Test, it was 1.293. Given that the mean score of the Pre-Test (29.333) is lower than that of the Post-Test (72.444), it can be inferred descriptively that there is a difference in learning outcomes between the two tests. However, to determine whether this difference is statistically significant, a paired sample t-test must be conducted. Based on the output of the Paired Samples Test, the Sig. (2-tailed) value was 0.000, which is less than 0.05. Therefore, H₀ is rejected, and H₁ is accepted, indicating that there is a significant effect of Mobile Learning assisted with Augmented Reality on improving students' creative thinking skills in the Salt Hydrolysis material.

Augmented Reality Integrated Mobile Learning Model to Train Creative Thinking Skills in Chemistry for High School Students

Based on the findings of the research, it was observed that the integration of Mobile Learning with Augmented Reality significantly enhanced students' creative thinking skills in the topic of Salt Hydrolysis. This research demonstrates that technological media can improve the quality of learning. The study conducted by Nasir & Fakhruddin (2023) identified four key factors contributing to enhanced student performance in Physics education: design, pedagogy, instructional materials, and media presentation techniques. Similarly, other studies have confirmed that mobile applications incorporating augmented reality significantly improve learning outcomes in Science and Technology courses, as evidenced by a 50% increase in

comprehension levels among 6th-grade primary and 1st-grade secondary students (experimental group).

Augmented Reality-based mobile applications promote self-directed learning, didactic instruction, and research (Gamboa-Ramos et al., 2021). Additional studies indicate that the combination of animated images, contrasting colors, and text in AR creates an enjoyable learning experience while enhancing memory retention (Nurhayati et al., 2022). AR objects, presented in two-dimensional forms resembling real-life events, enable students to better comprehend complex processes, providing opportunities for active exploration of the subject matter (Faridi et al., 2021).

This research has led to the development of a mobile learning model integrated with AR aimed at fostering creative thinking skills in high school Chemistry students. The model is an adaptation of the Pedagogical Mobile Learning Framework by Al-hunaiyyan et al. (2017), tailored to the specific findings of this study.

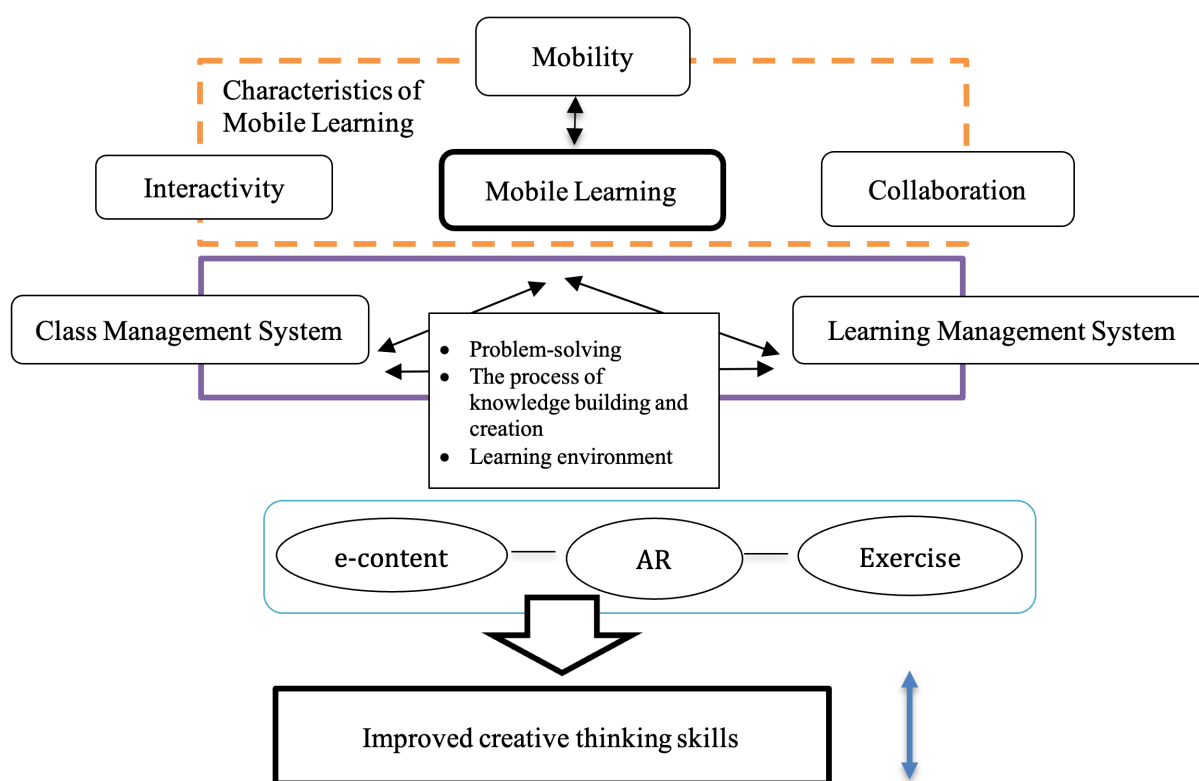


Figure 1. Augmented Reality Integrated Mobile Learning for Creative Thinking Skills

Figure 1 illustrates the components of augmented reality (AR)-integrated mobile learning, which facilitates the development of high school students' creative thinking skills. Initially, it is crucial to recognize that the key characteristics of mobile learning—mobility, interaction, and collaboration—must be implemented effectively. These characteristics align with the findings of Roopa & Taj (2021), who explain that mobile learning provides educators with increased mobility and interactivity with their students. Additionally, mobile learning fosters students' collaborative skills. Trust is an essential factor in teamwork and collaboration, which, in turn, enables students to solve problems collaboratively. This process enhances creative thinking as students and their groups are given the freedom to explore and discover new concepts. According to Rahman et al. (2022), students who demonstrate high academic achievement typically possess strong creative thinking skills. Hence, teachers must understand the technological media they employ to tailor the appropriate instructional strategies.

Secondly, mobile learning can be classified as a learning management system (LMS) that is inherently linked to classroom management. Students can commit to and utilize the LMS for collaborative learning. LMS platforms offer both teachers and students virtual classrooms that enhance the learning process by tracking students' progress and promoting collaborative learning (He & Diniz, 2014). However, high-quality learning outcomes cannot be achieved without effective classroom management. Therefore, AR-integrated mobile learning should be supplemented with face-to-face classroom management. Teachers who excel in classroom management can create an environment conducive to learning, where both teachers and students thrive. Over three decades of research have demonstrated that classroom management is a critical component of successful teaching (Marzano & Marzano, 2003). In this context, the role of mobile learning as an LMS is to support classroom management, allowing teachers to monitor and engage students beyond the traditional classroom setting, anytime and anywhere. Ultimately, technology simplifies tasks and enables teachers to manage their classrooms more efficiently.

This study reveals that the interplay between classroom management and LMS contributes to three key aspects: problem-solving, student engagement in knowledge construction, and the creation of a physical and contextual learning environment that nurtures creativity. These factors are instrumental in fostering students' creativity, particularly in learning chemistry. Teachers play a crucial role in cultivating creativity (Barbota et al., 2015) by providing creative learning opportunities in the classroom.

Problem-solving-based learning is a pedagogical approach that situates learning within the context of solving real-world problems (Wang et al., 2013). In problem-based learning, students engage with complex challenges, collaborate to find solutions, and reflect on their experiences, while teachers act as facilitators rather than information providers. Thus, problem-solving is highly relevant to fostering student creativity, as creativity involves observing, exploring possibilities, identifying problems, taking risks, learning from mistakes, rethinking, experimenting, solving problems, and sharing both processes and outcomes (James, 2015). This creative potential is realized when the classroom integrates a problem-solving approach, bridging the gap between classroom management and AR-integrated mobile learning through online discussion forums that can extend beyond face-to-face interactions.

Other researchers advocate for the use of online forums and tools to support learning through complex problem-solving (Liu & Tsai, 2008), with teachers guiding these discussions. Many studies have shown that teachers can encourage creativity by fostering open and supportive classroom environments, enabling students to build confidence and engage in learning. Additionally, teachers can create physical and contextual environments that promote creativity (Gregory et al., 2013; Beghetto & Kaufman, 2014; James, 2015; Fredagsvik, 2023). Other studies highlight the role of teachers as facilitators and collaborators who engage with students in the process of building and creating knowledge (Sawyer, 2004; Scardamalia & Bereiter, 2014; Fredagsvik, 2023).

The AR-integrated mobile learning platform offers students a rich learning experience through features such as e-content, AR, and exercises, which are not solely delivered by the teacher. The assignments provided via mobile platforms are tailored to students' talents, knowledge, and interests. Teachers design tasks that are challenging yet manageable, ensuring they are neither overwhelming nor discouraging.

By combining traditional classroom settings with mobile learning, teachers create a dual learning environment that reduces stress and promotes a fear-free learning atmosphere. The objectives are clear and well-defined, while progress is monitored through feedback that is informative rather than critical (James, 2015). Nasser et al. (2021) emphasize that LMS provides learners with consistent information regarding their performance, enabling students to track their progress. Even when final outcomes remain uncertain, teachers encourage

inquiry, exploration, and reward effort and competence, thereby facilitating the monitoring of creative thinking skills through mobile learning activities. The diversity of resources available in mobile learning further enriches students' experiences, offering a variety of meaningful learning activities.

Conclusion

This study has effectively enhanced students' creative thinking skills by utilizing a mobile learning model integrated with augmented reality (AR). The AR-enhanced mobile learning model developed in this research identifies the essential features of mobile learning and connects them to pedagogical principles, emerging from the integration of classroom management with a learning management system (LMS). This approach enriches students' experiences, as the learning environment is not confined to the classroom but extends to any time and place, allowing students to explore their creative thinking through problem-solving tasks. The integration of AR into mobile learning creates a unique learning experience, enabling students to construct knowledge more comprehensively than in a traditional classroom setting. However, teachers still play a crucial role in monitoring and supporting students' progress in developing creative thinking skills.

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