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STUDENTS' CONCEPTUAL UNDERSTANDING IN CHEMISTRY VIA AUGMENTED REALITY LEARNING CARDS

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ABSTRACT

Teaching abstract concepts in Chemistry has long been a challenge, particularly when students struggle to visualize microscopic processes. This study explored the effectiveness of augmented reality learning cards, named SmartcARd, a QR code–triggered augmented reality learning card system, in improving the conceptual understanding of Grade 9 students. A quasi-experimental pretest–posttest non-equivalent group design was employed during the academic year 2024–2025 at San Isidro College. Two intact heterogeneous classes participated in the study, with one group exposed to SmartcARd-integrated instruction and the other receiving non-SmartcARd teaching methods. A validated achievement test was used to measure students' conceptual understanding across selected Chemistry competencies. Descriptive statistics and Analysis of Covariance (ANCOVA) were utilized in analyzing the data. Findings showed that while both groups improved after instruction, students exposed to SmartcARd demonstrated greater gains. The SmartcARd group achieved higher posttest and retention scores in conceptual understanding and reached higher proficiency levels compared to the control group. ANCOVA results confirmed a statistically significant difference in favor of the SmartcARd group after controlling for pretest performance. The results suggest that integrating augmented reality learning tools such as SmartcARd can meaningfully enhance students' understanding of abstract Chemistry concepts and support more sustained learning.

Keywords: *augmented reality, chemistry education, conceptual understanding, SmartcARd*

INTRODUCTION

Understanding scientific concepts in Chemistry can be challenging for many students, particularly because many of these ideas involve processes and structures that cannot be directly seen. Concepts such as atoms, molecules, and chemical reactions often remain abstract when presented only through textbooks, diagrams, or verbal explanations. In response to this challenge, educational technologies have begun to play an important role in making science learning more meaningful and engaging. One emerging innovation is the use of augmented reality (AR), a technology that overlays digital objects onto the real world and allows learners to interact with scientific models in new ways. Through AR, students can explore three-dimensional representations of atoms, molecules, and chemical reactions, helping them visualize processes that are otherwise invisible and difficult to imagine. This interactive experience helps bridge the gap between abstract scientific explanations and concrete understanding (Ibáñez & Delgado-Kloos, 2018; Azuma et al., 2002).

Despite these developments, challenges in science education remain. Filipino students continue to perform below international standards in science. According to the 2022 PISA results, only 38% of students in the Philippines met the minimum level of science proficiency (OECD, 2022). Similarly, the 2019 TIMSS data revealed weak performance in areas that require application of knowledge (TIMSS and PIRLS, 2019). These findings point to persistent issues in helping students grasp complex topics such as atomic theory, bonding, and chemical reactions. In many schools, instruction is often limited to traditional lectures and textbook diagrams. As a result, students struggle to visualize and internalize abstract scientific concepts (Simbajon & Adlaon, 2024). Therefore, there is a growing need for instructional strategies that go beyond passive learning and support deeper conceptual understanding.

To address these challenges, researchers have explored the use of augmented reality to support learning in science. Studies show that AR improves conceptual understanding by allowing students to interact with three-dimensional representations of scientific structures and processes (Elford et al., 2023; Fitriana et al., 2024; Tarng et al., 2022). When learners are able to observe and manipulate models of atoms, molecules, and chemical reactions, they develop clearer mental representations of how these concepts work and how they are connected. Such interactive visualization helps students relate theoretical explanations to observable patterns, which can strengthen their conceptual understanding of scientific ideas (Solikhin et al., 2022; Yamtinah et al., 2023).

Nevertheless, existing research presents certain gaps. While AR has been widely studied in general STEM education (Pascual, 2021; Montalbo, 2021), there is still limited research specifically focused on QR code-triggered AR tools tailored to the Philippine Science 9 curriculum. Most studies either rely on expensive AR platforms or explore applications in different educational contexts (Akçayır & Akçayır, 2016). Moreover, there is a lack of low-cost, curriculum-aligned tools that can be realistically implemented in local classrooms. This gap presents an opportunity to develop practical and innovative resources for science education in the Philippines.

With these considerations, this study introduces an augmented reality learning card system named SmartcARd, designed to support the teaching of Chemistry concepts. SmartcARd uses printed cards with QR codes that link to web-based 3D AR models, allowing students to explore interactive representations of atoms, molecules, and other chemical structures using their smartphones. In schools where students have access to mobile devices but limited exposure to advanced learning technologies, this approach offers a practical and scalable instructional tool. Through these interactive models, students can better visualize abstract concepts and engage more actively in learning. Thus, this study examined the effectiveness of SmartcARd in enhancing Grade 9 students’ conceptual understanding in Chemistry while also supporting Sustainable Development Goal 4 by promoting accessible and innovative learning opportunities.

Research Questions

This study aimed to assess the potential of augmented reality learning cards, SmartcARd, an innovative instructional tool comprising printed cards embedded with QR codes that activate web-based 3D augmented reality models, in improving the conceptual understanding of Grade 9 Science students of San Isidro College.

Specifically, this study sought to answer the following questions:

1. What is the level of students' conceptual understanding when exposed to SmartcARd and those exposed to non-SmartcARd instruction in terms of:
   1.1 pretest;
   1.2 posttest; and
   1.3 retention test?
2. Is there a significant difference in the conceptual understanding of students exposed to SmartcARd and those exposed to non-SmartcARd instruction?

METHODOLOGY

Research Locale

The study was conducted in a private secondary school in Bukidnon, Philippines. The institution follows the Department of Education’s Science 9 curriculum and provides a suitable environment for integrating technology-supported instruction, as students have access to mobile devices for learning purposes.

Research Design

This study employed a quantitative research design using a quasi-experimental pretest–posttest non-equivalent group design. This design was utilized to determine the effect of augmented reality learning cards (SmartcARd) on students' conceptual understanding in Chemistry.

Two intact Grade 9 classes were used in the study. One class served as the experimental group, which received instruction supported by SmartcARd, while the other served as the control group, which received conventional instruction. Pretest, posttest, and retention measures were administered to evaluate changes in students' conceptual understanding over time.

Participants and Sampling

The respondents of the study were Grade 9 students enrolled in the Science 9 curriculum. A cluster sampling method was employed, wherein two intact classes were selected to preserve the natural classroom setting.

All students in the selected classes participated in the study, provided they were present during the major phases of data collection. Students who were absent during the administration of key assessments were excluded from the analysis to ensure consistency and reliability of the data.

Research Instrument

The study utilized a researcher-developed achievement test designed to measure students' conceptual understanding in Chemistry. The instrument covered selected second-quarter topics, including atomic structure, chemical bonding, and related concepts.

The test consisted of a combination of multiple-choice and open-ended items that required students to explain, analyze, and apply scientific concepts. Responses were evaluated using a scoring rubric aligned with the Department of Education's proficiency descriptors for conceptual understanding.

To ensure validity, the instrument underwent expert review by specialists in science education. Pilot testing was conducted prior to the actual study, and reliability analysis showed acceptable internal consistency, indicating that the instrument was appropriate for measuring conceptual understanding.

Intervention

The intervention was implemented over a four-week instructional period aligned with the second-quarter Chemistry topics. The instructional approach followed the regular classroom structure to ensure minimal disruption to the existing curriculum.

In the experimental group, SmartcARd was integrated into the teaching process as a supplementary learning tool that provided interactive visual representations of Chemistry concepts. These materials enabled students to engage with abstract concepts through guided classroom activities and discussions facilitated by the teacher.

The control group, on the other hand, received instruction using conventional teaching methods, including lectures, textbook-based explanations, and class discussions, without the integration of SmartcARd.

Both groups were taught the same content, followed the same schedule, and were handled under similar classroom conditions to ensure comparability of learning experiences.

Data Gathering Procedure

The data gathering process was carried out in a systematic and structured manner to ensure the accuracy, consistency, and reliability of the results. It consisted of three major phases: pretest, intervention, and posttest, followed by a retention phase.

At the initial stage, a pretest was administered to both the experimental and control groups to determine the students' baseline level of conceptual understanding in the selected Chemistry topics. The administration was conducted under standardized classroom conditions, with uniform instructions given to all participants to ensure fairness. The results of the pretest served as the basis for establishing the comparability of the two groups prior to the intervention.

Following the pretest, the intervention phase was implemented over a four-week instructional period. During this phase, both groups were taught the same Chemistry content aligned with the prescribed curriculum and schedule. The experimental group received instruction supported by SmartcARd, which provided interactive visual representations of abstract concepts to facilitate understanding. These materials were integrated into regular classroom activities such as guided discussions, concept exploration, and collaborative learning tasks. The teacher facilitated the learning process by guiding students' interaction with the materials and reinforcing key concepts throughout the lessons.

In contrast, the control group was taught using conventional instructional approaches, including lectures, textbook-based explanations, and class discussions. Efforts were made to ensure that both groups were exposed to similar content, time allocation, and learning objectives, differing only in the use of the instructional tool.

Throughout the intervention, the researcher monitored the implementation to ensure consistency in instructional delivery and student participation. Classroom activities were conducted in a structured manner to maintain alignment with the study objectives and to minimize potential sources of bias.

At the end of the intervention period, a posttest was administered to both groups using the same assessment instrument as the pretest. This allowed for the measurement of learning gains and comparison of conceptual understanding between the two groups after exposure to their respective instructional methods.

To further examine the retention of learning, a retention test was administered after a specified interval following the posttest. This phase aimed to determine the extent to which students were able to retain and sustain their conceptual understanding over time.

All test administrations were conducted under similar conditions, and student responses were collected and organized systematically for analysis. The use of consistent procedures across all phases ensured the reliability and validity of the data gathered in the study.

Data Analysis

Descriptive statistics, including mean and percentage scores, were used to determine the level of students' conceptual understanding.

To determine whether there was a significant difference between the experimental and control groups, Analysis of Covariance (ANCOVA) was employed, using pretest scores as the covariate. This statistical method allowed for a more accurate comparison of posttest results by controlling for initial differences between groups.

Scope and Limitations

This study focused on the conceptual understanding of Grade 9 students in selected Chemistry topics covered during the second quarter of the academic year. The investigation was limited to two intact classes within a single institution and did not include other grade levels or subject areas.

The study examined only one instructional intervention, namely SmartcARd-supported instruction, and compared it with conventional teaching methods. Other variables that may influence learning, such as students' motivation, prior knowledge beyond the pretest, and external learning resources, were not controlled.

Additionally, the duration of the intervention was limited to a four-week period, which may affect the generalizability of the findings over extended instructional durations.

RESULTS

This section presents the results of the study focusing on the conceptual understanding of students exposed to SmartcARd and non-SmartcARd instruction. The findings are organized according to the research questions and include both descriptive and inferential analyses.

Level of Students' Conceptual Understanding

Table 1. Students' Conceptual Understanding in SmartcARd and Non-SmartcARd Groups

Score	Percentage Score	SmartcARd						Non-SmartcARd						QD
		Pretest		Posttest		Retention test		Pretest		Posttest		Retention test		
		f	%	f	%	f	%	f	%	f	%	f	%	
54-60	90-100%	0	0	21	47.8	16	36.37	0	0	13	30.9	13	30.95	O
51-53	85-89%	0	0	13	29.5	12	27.27	0	0	7	16.7	6	14.29	VS
48-50	80-84%	0	0	5	11.4	8	18.18	0	0	10	23.8	9	21.43	S
45-57	75-79%	0	0	3	6.8	5	11.36	0	0	4	9.6	5	11.90	FS
0-44	Below 75%	44	100	2	4.5	3	6.82	42	100	8	19.0	9	21.43	DME
	Total	44	100	44	100	44	100	42	100	42	100	42	100	
	Mean	27.25		53.13		52.00		26.58		50.32		49.86		
	MPS	**45.42 (DME)**		**88.55 (VS)**		**86.67 (VS)**		**44.30 (DME)**		**83.87 (S)**		**83.10 (S)**		

Significant Difference in Conceptual Understanding in SmartcARd and Non-SmartcARd Groups

Table 2. ANCOVA of the Conceptual Understanding of SmartcARd and Non-SMC Groups

Group	N	Mean	SD
SmartcARd	44	53.134	4.307
Non-SmartcARd	42	50.319	6.047
Total	**86**	**51.759**	**5.388**

Source	SS	df	MS	f-value	p-value
Corrected Model	186.194[a]	2	93.097	3.388	.039
Intercept	4679.012	1	4679.012	170.257	.000
Pretest (Covariate)	15.910	1	15.910	.579	.449
Group	178.476	1	178.476	6.494	.013*
Error	2281.014	83	27.482		
Total	232863.390	86			
Corrected Total	2467.208	85			

**Significant at 0.05 level*

DISCUSSION

Level of Students' Conceptual Understanding

Table 1 presents the distribution of scores, mean scores, and mean percentage scores (MPS) of the SmartcARd and Non-SmartcARd groups across the pretest, posttest, and retention test. Prior to the intervention, both groups demonstrated low levels of conceptual understanding. The SmartcARd group obtained a mean score of 27.25 with an MPS of 45.42%, while the Non-SmartcARd group recorded a mean of 26.58 and an MPS of 44.30%. Both were interpreted as Did Not Meet Expectations (DME), with 100% of students in each group scoring below 75%. This similarity in baseline performance indicates that both groups started with comparable levels of prior knowledge in the second-quarter Chemistry topics.

Following the four-week intervention, noticeable improvements were observed in both groups; however, the increase was more pronounced in the SmartcARd group. The SmartcARd group achieved a posttest mean of 53.13 (MPS = 88.55%), interpreted as Very Satisfactory (VS). A large proportion of students (47.8%) reached the Outstanding level, while 29.5% attained Very Satisfactory performance. In contrast, the Non-SmartcARd group obtained a mean of 50.32 (MPS = 83.87%), interpreted as Satisfactory (S). Although improvements were evident, a smaller percentage of students in the Non-SmartcARd group reached the Outstanding level (30.9%), and more students remained within the Satisfactory and lower proficiency bands compared to the SmartcARd group.

This was also noticeable during the actual classroom sessions. Students in the non-SmartcARd group were generally able to follow the lesson, but many of them depended heavily on the teacher's explanations and the textbook diagrams. When topics became more abstract, such as atomic structure or bonding, some students seemed unsure and had difficulty visualizing what was being discussed.

During class activities, several students gave answers that were correct but lacked depth. Their responses were often brief, and when asked to explain further, they hesitated or needed additional prompting. It was also observed that participation was not as consistent, with only a few students actively engaging in discussions while others remained passive or waited for the answers to be explained.

In more complex or situational questions, many students tended to recall information rather than explain it in their own words. This suggests that while they were able to understand the basic ideas, they were not always able to fully process or apply the concepts at a deeper level. These classroom observations help explain why a larger number of students remained in the Satisfactory level, as they showed improvement but had not yet reached the level of mastery demonstrated by the SmartcARd group.

The retention test results further reinforced this pattern. The SmartcARd group maintained a high mean score of 52.00 (MPS = 86.67%), retaining its Very Satisfactory (VS) level of performance. Meanwhile, the Non-SmartcARd group obtained a slightly lower mean of 49.86 (MPS = 83.10%), remaining within the Satisfactory (S) category. Notably, the SmartcARd group exhibited stronger retention, with 36.37% of students still performing at the Outstanding level, compared to 30.95% in the Non-SmartcARd group. Moreover, fewer students in the SmartcARd group regressed to the Did Not Meet Expectations category compared to the control group.

This was also evident during the retention phase, where students in the SmartcARd group were generally more confident in recalling and explaining previously learned concepts. Even after some time had passed, many of them were still able to describe chemical structures and processes with minimal assistance, suggesting that their understanding was retained rather than simply memorized.

In contrast, some students in the Non-SmartcARd group appeared to struggle in recalling key ideas during the retention test. A few students showed signs of confusion or uncertainty, particularly when asked to explain concepts that required deeper understanding. During follow-up discussions, it was observed that they tended to forget specific details or mix up concepts, indicating that their earlier learning was not fully retained.

These observations suggest that the use of SmartcARd may have helped students form more lasting mental representations of abstract concepts. Because they were able to interact with and visualize the material during the intervention, their learning appeared to be more stable over time. This may explain why fewer students in the SmartcARd group fell back to lower performance levels compared to those who relied solely on non-SmartcARd instruction.

Taken together, these results indicate that while both instructional approaches led to improvements in conceptual understanding, exposure to SmartcARd resulted in higher levels of mastery and stronger knowledge retention. The consistent movement of students from the DME category in the pretest to predominantly Very Satisfactory and Outstanding levels in the posttest and retention test suggests that the integration of QR code-triggered augmented reality models facilitated deeper conceptual learning.

This finding aligns with the literature discussed in the previous chapter. Conceptual understanding in science requires students to construct meaningful mental models and connect abstract concepts to observable representations (Mi et al., 2020; Mulyono & Hapizah, 2018). Traditional lecture-based approaches often limit students' ability to visualize microscopic structures such as atomic arrangements and molecular bonding (Osborne, 2022; Üce & Ceyhan, 2019). In contrast, augmented reality enables learners to interact with three-dimensional models, thereby strengthening mental model construction and reducing misconceptions (Ibáñez & Delgado-Kloos, 2018; Yoon et al., 2017). The stronger performance of the SmartcARd group supports previous findings that AR-based chemistry tools significantly enhance students' conceptual understanding of molecular structures and bonding (Solikhin et al., 2022; Tarng et al., 2022; Yamtinah et al., 2023).

Furthermore, the sustained performance observed in the retention test conducted after two-weeks suggests that SmartcARd did not merely improve short-term recall but contributed to longer-term knowledge consolidation. According to Cognitive Load Theory (Sweller, 1988), learning materials that reduce unnecessary cognitive burden and present information visually can enhance schema construction and retention. The interactive 3D models embedded in SmartcARd likely helped students organize and encode information more effectively compared to static textbook diagrams. Similarly, constructivist learning principles emphasize active engagement and experiential interaction as essential for durable understanding (Piaget, 1954; Vygotsky, 1978). Through allowing students to manipulate atomic and molecular models directly, SmartcARd may have promoted deeper cognitive processing, which in turn strengthened conceptual retention.

Significant Difference in Conceptual Understanding in SmartcARd and Non-SmartcARd Groups

To determine whether the observed differences in posttest scores were statistically significant after controlling for initial differences, an Analysis of Covariance (ANCOVA) was conducted using pretest scores as the covariate.

The descriptive statistics show that the SmartcARd group obtained a higher adjusted posttest mean ($M = 53.134$, $SD = 4.307$) compared to the Non-SmartcARd group ($M = 50.319$, $SD = 6.047$). Although both groups demonstrated improvement from the pretest phase, the SmartcARd group achieved a noticeably higher mean performance in the posttest.

The ANCOVA results revealed that the effect of group membership on posttest conceptual understanding was statistically significant, $F(1, 83) = 6.494$, $p = .013$, at the 0.05 level of significance. Since the computed p-value is less than .05, the null hypothesis stating that there is no significant difference between the two groups is rejected. This indicates that exposure to SmartcARd-integrated instruction had a significant effect on students' conceptual understanding in Chemistry when compared to non-SmartcARd instruction alone. The significance of this finding suggests that the higher performance of the SmartcARd group cannot be attributed merely to chance or initial ability differences. Rather, the augmented reality learning cards appear to have contributed meaningfully to students' conceptual development. Conceptual understanding requires learners to build coherent mental models and connect abstract scientific ideas to observable representations (Mi et al., 2020; Mulyono & Hapizah, 2018). Traditional instructional approaches often rely on static diagrams and verbal explanations, which may limit students' ability to fully internalize microscopic chemical processes (Üce & Ceyhan, 2019; Osborne, 2022). In contrast, augmented reality environments allow students to interact with three-dimensional molecular structures, strengthening visualization and supporting deeper cognitive processing (Ibáñez & Delgado-Kloos, 2018).

The present findings further align with studies in Chemistry education demonstrating that AR-based tools significantly enhance conceptual understanding compared to conventional methods (Solikhin et al., 2022; Tarng et al., 2022; Yamtinah et al., 2023). These studies emphasize that interactive 3D representations promote accurate mental model formation and reduce misconceptions, particularly in topics involving molecular geometry and bonding. The SmartcARd intervention mirrors these mechanisms, as students were able to manipulate atomic models directly through QR-triggered AR visualization.

The results also support the theoretical framework of the study. Constructivist Learning Theory posits that knowledge is actively constructed through interaction and experience (Piaget, 1954; Vygotsky, 1978). SmartcARd created opportunities for such interaction, enabling learners to explore relationships among chemical structures rather than passively receive information. Cognitive Load Theory further explains that instructional materials that present information visually and interactively can reduce extraneous cognitive load and facilitate schema construction (Sweller, 1988). The statistically significant improvement observed in the SmartcARd group suggests that the integration of AR models enhanced meaningful learning rather than superficial memorization.

Conclusions

Based on the findings of the study, the following conclusions were drawn:

The findings demonstrate that the integration of SmartcARd into Chemistry instruction led to higher levels of conceptual understanding among Grade 9 students. Although both groups showed improvement after the instructional period, students exposed to SmartcARd achieved stronger mastery of abstract concepts and sustained their performance in the retention test. This suggests that the augmented reality–integrated approach facilitated deeper comprehension and more durable learning compared to non-SmartcARd method.

Moreover, the findings demonstrate that the SmartcARd intervention significantly improved students’ conceptual understanding in Chemistry. Even after accounting for initial differences in pretest performance, students exposed to SmartcARd consistently performed better than those who received non-SmartcARd instruction. This indicates that the observed improvement can be attributed to the use of the SmartcARd learning tool.

Recommendations

Based on the findings, several recommendations are proposed:

In light of the improvement in students’ conceptual understanding, Science teachers are encouraged to integrate augmented reality tools such as SmartcARd, especially when teaching abstract topics that require visualization. Using interactive 3D models can help students grasp complex ideas more clearly and retain them longer.

Given the significant differences between instructional approaches, schools may consider supporting the integration of augmented reality into Science classes. Providing training and access to appropriate technological resources will help ensure that these tools are used effectively and aligned with learning objectives.

Compliance with Ethical Standards

The researcher adhered to all ethical standards throughout the study. Informed consent was obtained from participants and their parents or guardians prior to data collection, and participation was voluntary with the right to withdraw at any time without penalty. Anonymity and confidentiality were strictly maintained, and all data were handled in accordance with the Data Privacy Act. Permission to conduct the study was secured from the appropriate school authorities.

Participants were assured that their responses would be used solely for research purposes. Their well-being was safeguarded, and no disruption to regular instruction occurred. The researcher declares no conflict of interest and reports findings honestly and without bias. All sources were properly acknowledged to avoid plagiarism, and results were used strictly for academic purposes. The use of AI tools was limited to language refinement, while all interpretations and analyses remain the researcher's original work.

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