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# The Impact of Augmented Reality on Learning Outcomes and Learning Interest in Natural Science Subjects

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*Abstract* - **Augmented Reality (AR) has been recognized as a promising technology for supporting science learning through interactive three-dimensional visualization. However, empirical evidence on its effects within competency-based interdisciplinary curricula - particularly in lower secondary contexts where teacher accessibility and infrastructure constraints are significant - remains limited. This study examines the effects of AR-supported instruction on Grade 6 students' learning interest, immediate achievement, and short-term knowledge retention in Natural Science. It proposes a structured pedagogical framework for its implementation. A quasi-experimental design was employed with 65 sixth-grade students (experimental group: n = 30; control group: n = 35) from a public lower secondary school in Thai Nguyen Province, Vietnam. AR learning materials were developed using CoSpaces Edu across seven Natural Science topics and integrated through a four-step implementation process and a three-stage instructional model. Learning outcomes were measured via immediate and two-week delayed post-tests aligned with Bloom's taxonomy, and learning interest was assessed using a ten-item Likert-scale questionnaire demonstrating acceptable internal consistency ($\alpha = 0.793$). Results showed that the experimental group significantly outperformed the control group on both assessments (immediate: M = 8.2 vs. 7.5; delayed: M = 7.8 vs. 6.7). One-way ANOVA confirmed statistically significant between-group differences ($F(1, 63) = 12.190$, $p = 0.001$, $\eta^2 = 0.162$), and survey data indicated strong student engagement and perceived learning benefit. These findings suggest that when AR is embedded in a structured pedagogical process on an accessible platform, it can enhance both short-term achievement and knowledge retention in Natural Science education for schools navigating digital transformation under the 2018 Vietnamese General Education Curriculum.**

*Keywords* - **Augmented Reality (AR), Natural Science, learning interest, learning outcomes, CoSpace Edu.**

*JEET Category* - **Research.**

## I. INTRODUCTION

According to Johnstone's research, students often need help understanding abstract scientific concepts if they rely solely on verbal descriptions or textbooks (Johnstone, 1991). Scientific phenomena frequently occur on tiny scales (such as atomic particles) or very large scales (such as the universe), making them difficult for students to visualize. Gilbert has emphasized the importance of models and diagrams in helping students visualize complex scientific phenomena (Gilbert, 2005). Learning through theory and textbooks can lack interaction and real-world experience, reducing motivation to learn. Although teachers often use diagrams, physical models, and verbal descriptions, these tools might not fully arouse students' curiosity and promote active learning engagement (Kaur et al., 2020). Hake's research has shown that interactive teaching methods can significantly improve students' understanding of scientific concepts (Hake, 2002).

In Vietnam, in the Comprehensive General Education Program 2018, the Natural Science subject has been built and developed on the foundation of the following scientific disciplines: Physics, Chemistry, Biology, and Earth Science in a dialectical relationship with other sciences such as Mathematics and Informatics. This knowledge and these skills have been organized according to content threads (matter and its transformations, living things, energy and transformations, the Earth and the Sky), reflecting the general principles and natural laws (structural properties, diversity, interaction, systemic nature, laws of motion and transformation), while gradually reflecting the role of natural science in social development and the application of natural science knowledge and skills in the sustainable use and exploitation of natural resources (Ministry of Education and Training, 2018). The Natural Science subject has been developed from the Science subject at the primary school level and is considered compulsory. Natural science combines theory and

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experimentation seamlessly. Therefore, practical work, experiments, observations, and analysis play a significant role and are regarded as characteristic teaching and learning methods for this subject.

Learning interest is an intrinsic motivation that encourages students to do what they want to positively impact their academic performance (Muhammad et al., 2023). This new general education curriculum also mentions interest as one of the personal attributes that helps students develop their capabilities. Enhancing students' learning interests is also one of the objectives mentioned in the education curriculum (Nguyen et al., 2024). Learning interest motivates students' active and proactive exploration and creativity in the learning process. Therefore, enhancing students' interest in the teaching process is necessary. There have been many studies on improving interactive teaching methods to increase learning interest, especially for subjects considered abstract, like Natural Science. These include techniques such as using educational games (Malgard et al., 2023), project-based learning combined with mobile technology (Zhang & Hwang, 2023), and the recent use of virtual learning environments in teaching (Familoni & Onyebuchi, 2024).

Along with technology development, AR is applied in many fields owing to its capabilities to integrate digital information with the user's environment in real-time to visually modify the natural environment or provide additional information to the user. According to Akçayır's research, AR is an engaging technology that can make the invisible visible to support learners' understanding of concepts that generally cannot be observed. In other words, learners can use AR to explore more complex concepts interactively and engagingly (Akçayır & Akçayır, 2017). Dunleavy and colleagues investigated the use of AR in science education and found that AR can create a rich learning environment and enhance learning motivation, helping students better understand complex concepts (Dunleavy et al., 2009). Indeed, Bacca *et al.* affirmed that AR can increase students' engagement, motivation, and learning interest and improve learning outcomes in natural science subjects (Bacca Acosta et al., 2014).

AR has shown considerable potential for supporting interactive and visually rich science learning environments. Prior studies have reported positive effects of AR on students' engagement, motivation, conceptual visualization, and academic achievement. However, the educational value of AR should not be understood merely as a technological novelty. For AR to contribute meaningfully to science education, it needs to be embedded in a pedagogically structured learning process and evaluated through both affective and cognitive outcomes.

In the Vietnamese context, the 2018 General Education Curriculum emphasizes competency-based learning, interdisciplinary integration, and the development of students' active inquiry in Natural Science. These requirements create a strong need for feasible technology-supported instructional models that can help teachers visualize abstract scientific concepts while remaining compatible with existing school conditions. Although previous AR studies in Vietnam have examined science learning outcomes in specific topics and at multiple assessment points, further evidence is still needed on how AR can be integrated into the Grade 6 interdisciplinary Natural Science curriculum through a teacher-accessible platform and how such integration relates to students' learning interest, immediate achievement, and short-term knowledge retention.

To address this need, this study makes three specific contributions. First, it provides context-specific empirical evidence on AR-supported Grade 6 Natural Science learning by jointly examining students' learning interest, immediate learning outcomes, and knowledge retention measured through a two-week delayed post-test. Second, it proposes a structured AR integration workflow using CoSpaces Edu, a platform that allows teachers to design interactive 3D learning materials without requiring advanced programming skills. Third, it develops practical implementation recommendations concerning content selection, teacher preparation, classroom organization, technical conditions, assessment, and post-class consolidation, thereby making the proposed AR approach more operational for lower secondary schools in Vietnam.

To achieve these objectives, the study focuses on addressing three research questions:

*RQ1.* How does AR integration through CoSpaces Edu influence Grade 6 students' learning interest, engagement, and immediate learning outcomes in Natural Science?

*RQ2.* To what extent do students in an AR-supported learning environment differ from those in a conventional learning environment in terms of knowledge retention measured by a two-week delayed post-test?

*RQ3.* What pedagogical and practical conditions are needed to implement AR effectively in Grade 6 Natural Science lessons under the current school context in Vietnam?

This research not only provides empirical evidence for the effectiveness of AR but also establishes an optimal instructional model, contributing to the development of a substantive digital transformation roadmap for lower secondary education.

## II. Literature Review

The integration of AR in the teaching of Natural Science has been considered from the preschool (Cascales et al., 2013) to primary (Anggara et al., 2021), (Midak et al., 2020) and Middle school (Wang & Chi, 2012), (Trần et al., 2023) levels. The studies indicate that the use of AR helps increase students' interest, focus, and interaction, enhances their imagination and self-learning abilities (Erwis et al., 2024), helps visualize abstract and difficult-to-conceptualize concepts and phenomena, improves students' recognition and understanding of complex scientific concepts compared to traditional methods, and allows students to more easily access and gain a more profound knowledge of abstract scientific content (Yulianti et al., 2021). AR provides a more visual and comprehensive perspective on learning content (Akçayır & Akçayır, 2017). Using AR in teaching and learning enables the creation of a virtual interactive environment through 3D models, allowing students to engage in the learning process more dynamically and engagingly, thereby actively enhancing their learning capabilities. The potential of exploiting AR in teaching and learning, as well as the impact of integrating AR on improving students' learning interest in the Natural Science, are manifested through the following educational content:

*Chemistry Education*

In chemistry, AR is a new and promising tool that helps teachers create more diverse and enriched chemistry lessons, allowing them to develop applications and games with a highly realistic virtual environment from various perspectives, assisting students to quickly conceptualize and deeply understand chemical concepts, as well as actively participate and interact. For example, AR applications can turn a chemistry lesson on chemical reactions into a simulation game, allowing students to observe the results directly on their devices, creating an engaging and interactive learning environment. AR also enables the creation of 3D molecular models, allowing students to interact visually and gain a deeper understanding of chemical structures and properties (Liu et al., 2023).

*Physics Education*

AR can be used to visualize complex phenomena and abstract concepts such as physical laws, optical phenomena, and topics related to magnetism. Using AR in teaching creates curiosity and excitement for students, stimulates creativity and critical thinking, and improves learning and practical skills. For example, AR can simulate physical experiments that may be too dangerous, expensive, or impractical to perform in a school laboratory. Students can visualize and interact with 3D models of force fields, electromagnetism, or quantum particles, enhancing their understanding of these concepts (Ferdiman et al., 2023). AR applications can illustrate the principles of mechanics, optics, and thermodynamics more engagingly and tangibly, promoting active learning and curiosity (Rahmat et al., 2023).

*Biology Education*

In biology, AR can bring to class the study of anatomy, ecosystems, and cellular processes. AR significantly improves students' understanding of the basic anatomy and physiology of the human heart and circulatory system and the impact of adrenaline on the human circulatory system (Gnidovec et al., 2020). AR can also simulate ecosystems, demonstrating the interactions between different species and their environments. Furthermore, integrating AR might enhance the study of genetics by allowing students to manipulate DNA sequences and observe the effects of genetic mutations, cellular processes, and cell division (Özeren & Top, 2023). AR applications help innovate biology teaching methods in schools, providing students with opportunities to observe, learn, and practice biology directly on smart devices in a highly visual, dynamic, and engaging way. This brings the subject matter closer to the learner, helping them connect with the lessons. As a result, students become more interested and inspired and develop creative thinking in biology.

*Earth Science*

AR technology is increasingly being applied to teaching Earth Science. This content area is complex for students to visualize, and it challenges teachers to effectively convey the knowledge required to develop competencies according to the 2018 General Education Curriculum (Ministry of Education and Training, 2018). However, the application of AR in teaching this content has enhanced the real-life experiences for students, making the learning process more dynamic and easier to understand while fostering students' self-learning abilities (Wang & Chi, 2012). By using AR, students can observe the effects of changes in the distance between the Earth and the Moon, dynamic 3D images focusing on the two celestial bodies (Lindner et al., 2019), 3D models of the Earth's layers, lessons on the solar system, astronomical phenomena like solar and lunar eclipses, and the movements of planets (Yıldırım & Kapucu, 2020), and more.

Alongside the potential and impact of AR in teaching the aforementioned educational content, research has also identified some specific difficulties and challenges in implementing AR technology in teaching natural science subjects, including significant investment in technological infrastructure such as computers, mobile devices, and appropriate AR software (Anggara et al., 2021), the synchronization and compatibility between various AR devices and applications (Trần et al., 2023). In addition, there are issues related to digital competence, as teachers require training on using and integrating AR technology into their teaching, and students may also need help using the technology (Cascales et al., 2013). Also, the relevant AR content and resources are scarce and aligned with the curriculum and student skill levels (Erwis et al., 2024), leading to challenges in developing and integrating AR applications into the teaching process (Yulianti et al., 2021). From this, it is clear that further research is needed to evaluate the effectiveness and impact of AR in natural science teaching (Midak et al., 2020) and measures to ensure the quality of AR applications used in instruction.

Extant literature has established a robust foundation, demonstrating AR potential to enhance student engagement, visualization capabilities, and learning motivation across diverse Natural Science domains. However, several critical limitations warrant further consideration. First, there is a distinct lack of objective measurement. The majority of current studies over-rely on surveying self-reported interest and learner satisfaction. Consequently, there is a dearth of rigorous empirical comparisons verifying whether increased engagement effectively translates into tangible improvements in actual academic performance and problem-solving competencies. Second, there is an absence of data regarding long-term retention. Reported findings are frequently based on assessments conducted immediately following technological interventions, raising concerns about the 'novelty effect'—whereby students participate actively due to the tool’s novelty rather than pedagogical depth. The lack of delayed post-tests conducted after a specific duration means the sustainability of AR in knowledge retention remains an open question. Finally, a disconnect often exists between technological tools and local pedagogical contexts. Despite the availability of powerful AR tools, research in Vietnam has yet to propose a specific and feasible pedagogical workflow that aligns with the learning outcomes and requirements of the 2018 Integrated Natural Science Curriculum mandated by the Ministry of Education and Training.

Hence, this research aims to evaluate AR technology's effectiveness in teaching natural science and explore the impact of AR on enhancing middle school students' interest in learning natural science subjects. It also aims to analyze the challenges in integrating AR into the curriculum of natural science subjects in Vietnam. Based on the findings, the research proposes methods for incorporating AR into teaching to create a richer and more diverse learning experience.

## III. RESEARCH METHODOLOGY

### A. Research design

This study employed a quasi-experimental design with an experimental group and a control group. The independent variable was the use of AR applications in Grade 6 Natural Science lessons, while the dependent variables included students' learning interest, immediate learning outcomes, and short-term knowledge retention.

The participants were 65 sixth-grade students from Doc Lap Middle School, Thai Nguyen City, Thai Nguyen Province, Vietnam. Two intact classes were selected for the pedagogical experiment. One class was assigned as the experimental group, consisting of 30 students, while the other served as the control group, consisting of 35 students. The experimental group learned selected Natural Science topics with AR support, whereas the control group learned the same content through conventional instructional methods without AR support.

Due to the school's existing class organization and timetable constraints, individual random assignment was not feasible. Therefore, intact classes were used, and the study should be interpreted as a quasi-experimental investigation rather than a randomized controlled trial. The two classes were considered comparable in terms of grade level, school context, learning content, and basic digital familiarity. As shown in Table I, all students in both groups reported being proficient in smartphone use, which helped reduce differences related to basic technology manipulation.

TABLE I
SAMPLE CHARACTERISTICS OF THE PEDAGOGICAL EXPERIMENT

| Group | N | Gender | | Smartphone-use proficiency | |
|---|---|---|---|---|---|
| | | Male | Female | Proficient | Incompetent |
| Experiment | 30 | 18 | 12 | 30 (100%) | 0 (0%) |
| Control | 35 | 19 | 16 | 35 (100%) | 0 (0%) |

### B. AR intervention

Various tools can be used to design AR learning materials, such as CoSpaces Edu, Layar, Aurasma/HP Reveal, Unity 3D, Unreal Engine, ARKit, ARCore, and Vuforia. In this study, CoSpaces Edu was selected to design AR-supported learning materials for selected Grade 6 Natural Science lessons. CoSpaces Edu was chosen because it is easy to use, does not require advanced programming skills, provides templates and tutorials, and supports multimedia integration. These characteristics make it suitable for lower secondary school teachers who need an accessible platform for integrating AR into classroom teaching.

The AR intervention was designed for Natural Science topics that involve abstract, dynamic, or difficult-to-observe phenomena. The selected topics included states of matter, separation of substances from mixtures, cell structure, diversity of living organisms, force, energy transformation, and the solar system. These topics were considered appropriate for AR integration because they benefit from 3D visualization, interactive manipulation, and simulation of scientific processes.

In the experimental group, AR was integrated into the learning process through three stages: pre-class preparation, guided in-class AR exploration, and post-class consolidation. Before class, the teacher selected suitable content, prepared AR materials on CoSpaces Edu, and provided instructions for students to access and use the AR environment. During class, students interacted with 3D models, observed simulated scientific phenomena, discussed their observations, and completed learning tasks under teacher guidance. After class, students completed review and reflection activities to reinforce conceptual understanding.

The control group learned the same Natural Science content within the same instructional period but without AR-supported materials. Conventional instruction included textbook-based explanation, teacher demonstration, questioning, classroom discussion, and regular learning exercises. This arrangement was intended to compare AR-supported instruction with conventional teaching while keeping the learning content and instructional duration comparable between the two groups.

### C. Research instruments

Three main instruments were used in this study: achievement tests, a student questionnaire, and open-ended questions for students and teachers.

First, students' learning outcomes were measured using an immediate post-test administered after the completion of the lessons. To examine short-term knowledge retention, the same or equivalent memory recall test was administered again two weeks later. The test items were designed with reference to the revised Bloom's taxonomy, focusing on C3 Apply, C4 Analyze, and C5 Evaluate levels. These levels were selected because the study aimed not only to examine students' recall of factual knowledge but also their ability to apply, analyze, and evaluate scientific concepts after learning.

Second, a student questionnaire was used to evaluate students' learning interest and perceptions of AR-supported Natural Science lessons. The questionnaire consisted of ten Likert-scale items, ranging from 1 = Strongly Disagree to 5 = Strongly Agree. The items measured students' perceived interest, engagement, enjoyment, understanding, concentration, motivation, perceived retention, and willingness to continue using AR in Natural Science lessons.

TABLE II
STUDENT QUESTIONNAIRE ON LEARNING INTEREST AND PERCEPTIONS OF AR-SUPPORTED NATURAL SCIENCE LESSONS

| Code | Question |
|---|---|
| S.Q1 | Using AR makes Natural Science lessons more interesting. |
| S.Q2 | 3D models created with AR increase my interest in Natural Science lessons. |
| S.Q3 | I am more actively participating in Natural Science learning activities with AR. |
| S.Q4 | Using AR makes me enjoy learning Natural Science more. |
| S.Q5 | Integrating AR helps me better understand concepts and processes in Natural Science. |
| S.Q6 | I like using AR to explore Natural Science topics more deeply. |
| S.Q7 | Combining AR helps me focus more on Natural Science lessons. |
| S.Q8 | Using AR helps me remember Natural Science knowledge better than traditional learning methods. |
| S.Q9 | Using AR increases my motivation to learn Natural Science. |
| S.Q10 | I want to use AR more often in Natural Science lessons. |

Third, open-ended questions were included to collect qualitative feedback from students and teachers. The student questions focused on why AR made Natural Science lessons more interesting and what students expected from future AR-supported learning.

*S.QO1: Please explain why you feel more interested in Natural Science when AR is integrated into lessons.*

*S.QO2: Please describe your expectations for using AR technology to improve your Natural Science learning.*

The teacher questions explored teachers' perceptions of AR use, observed changes in students' interest and participation, support needed for AR implementation, and suggestions for improving AR-supported Natural Science teaching.

TABLE III
OPEN-ENDED QUESTIONS FOR TEACHERS REGARDING AR-SUPPORTED NATURAL SCIENCE TEACHING

| Code | Question |
|---|---|
| T.QO1 | How do you evaluate the use of AR technology in Natural Science lessons? |
| T.QO2 | Have you noticed any changes in students' interest and participation in learning when using AR compared to traditional lessons? Please share specific observations. |
| T.QO3 | Do you need any help in preparing and implementing AR technology in teaching? |
| T.QO4 | Do you suggest using AR to teach Natural Science more effectively? |

To ensure content validity, the questionnaire and achievement tests were reviewed by Natural Science education experts and experienced secondary school teachers. The review focused on the alignment between the instruments, the Grade 6 Natural Science learning objectives, and the intended constructs of learning interest, engagement, conceptual understanding, and knowledge retention.

To further evaluate the reliability of the student questionnaire, Cronbach's alpha was calculated based on responses from the 30 students in the experimental group. As presented in Table IV, the coefficient exceeded the minimum acceptable threshold, supporting the internal consistency of the instrument.

TABLE IV
RELIABILITY OF THE STUDENT QUESTIONNAIRE

| Instrument | Items | N | Cronbach's α | Reliability level |
|---|---|---|---|---|
| S.Q1–S.Q10 | 10 | 30 | 0.793 | Acceptable |

This result indicates that the items functioned as a reliable and internally consistent scale, supporting its suitability as a measurement instrument in the present study (Nunnally, 1975).

### D. Data analysis

Quantitative data were analyzed using IBM SPSS Statistics 26. Descriptive statistics, including frequency, percentage, mean score, and achievement rate, were used to summarize students' questionnaire responses and test results. ANOVA was conducted to examine differences in learning outcomes between the experimental and control groups. In addition to statistical significance, eta squared ($\eta^2$) was calculated to estimate the effect size of the AR intervention. Qualitative responses from students and teachers were summarized thematically. Python was used to generate visual charts for presenting the results.

## IV. RESULTS AND DISCUSSION

### A. AR Integration and Implementation

Based on the AR-supported mobile learning procedure proposed by Erwis et al., 2024 and the lesson planning framework specified in Official Dispatch No. 5512 of the Ministry of Education and Training of Vietnam, this study proposed an AR integration process for Grade 6 Natural Science teaching, as shown in Fig. 1. The process consists of four main stages: selecting suitable content, designing AR learning materials, integrating AR into teaching and learning activities, and evaluating and improving the implementation. This process was designed to ensure that AR is not used merely as a visual demonstration tool but as a pedagogical support integrated into lesson objectives, classroom interaction, and learning assessment.

As shown in Fig. 1, the first stage requires teachers to identify abstract, dynamic, microscopic, macroscopic, or difficult-to-observe scientific concepts for which AR can provide clear visual and interactive value. The second stage focuses on developing appropriate 3D models, animations, and simulations. The third stage emphasizes the integration of AR into classroom activities, including teacher guidance, student exploration, discussion, and practice. The final stage involves collecting feedback, evaluating learning outcomes, and revising AR materials and instructional strategies for future lessons.

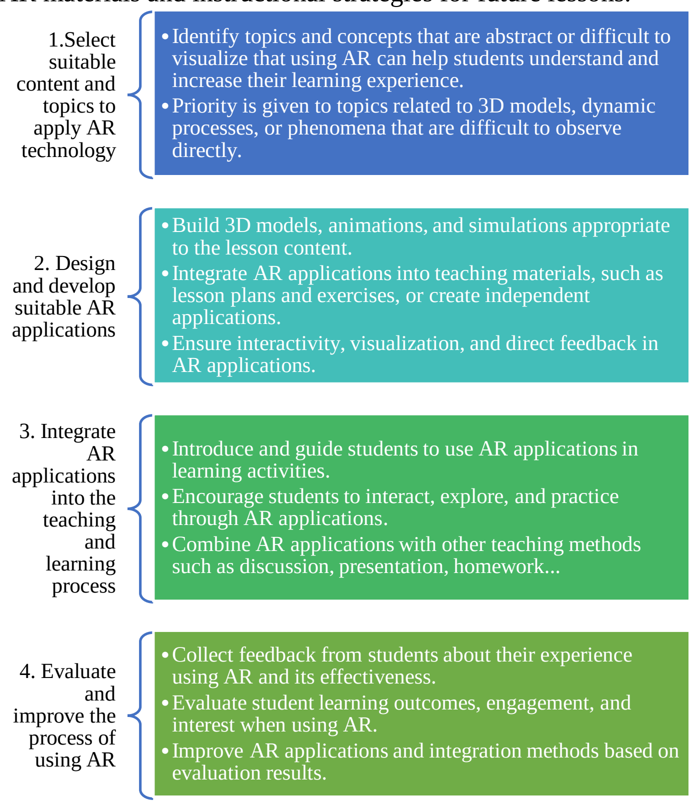



Fig. 1. Proposed process of integrating AR technology into teaching Natural Science

To operationalize the integration process in classroom practice, this study further proposed a teaching organization model consisting of three stages: pre-class preparation, during-class AR exploration, and after-class consolidation, as shown in Fig. 2. This model clarifies the roles of teachers and students before, during, and after AR-supported lessons. It also helps ensure that teacher guidance, learning tasks, discussion, and follow-up activities accompany students' interaction with AR materials.

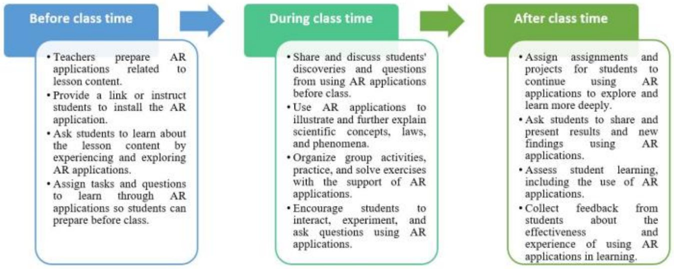


Fig. 2. Proposed teaching organization process with the support of AR technology in teaching Natural Science

## *B. AR Learning Materials*

To make the proposed AR integration model more practical for teachers and school administrators, Table V summarizes key implementation recommendations for Grade 6 Natural Science lessons. These recommendations translate the proposed framework into concrete actions related to content selection, teacher preparation, classroom organization, technical conditions, assessment, and post-class consolidation.

TABLE V
PRACTICAL RECOMMENDATIONS FOR AR IMPLEMENTATION IN GRADE 6 NATURAL SCIENCE

| Component | Practical Recommendation | Purpose |
|---|---|---|
| Content selection | Prioritize topics involving abstract, dynamic, or difficult-to-observe phenomena (e.g., states of matter, cell structure, force, energy transformation, solar system) that benefit from 3D visualization and interactive simulation. | Ensures AR is applied where it adds the greatest pedagogical value rather than as a generic add-on. |
| Teacher preparation | Provide structured guidance and short training sessions on using CoSpaces Edu to design and adapt AR materials without requiring programming skills; build a shared library of ready-to-use AR content aligned with the curriculum. | Reduces the technical burden on teachers and supports sustainable, scalable implementation. |
| Classroom organization | Implement the three-stage teaching model (pre-class preparation, in-class guided AR exploration, post-class consolidation), clearly assigning teacher and student roles at each stage (see Fig. 2). | Embeds AR within a pedagogically structured process rather than as an isolated demonstration tool. |
| Technical conditions | Ensure stable internet connectivity and adequate mobile devices, and provide on-site technical support during lessons; pilot-test AR materials before classroom use. | Minimizes technical disruptions that could undermine the learning experience, as noted in students' feedback. |
| Assessment | Combine immediate and two-week delayed post-tests with formative observation of student engagement during AR activities. | Captures both cognitive gains and short-term retention, avoiding reliance on a single assessment point. |
| Post-class consolidation | Assign reflection and review tasks connecting AR-based exploration to the theoretical content in the textbook. | Reinforces conceptual understanding and mitigates the risk of engagement without deep learning. |

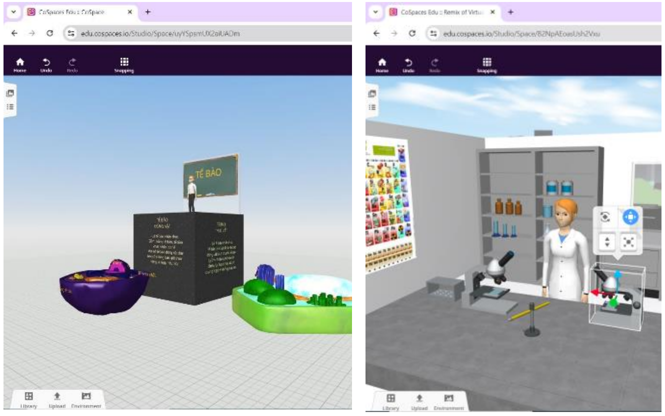
In addition to these cross-cutting implementation recommendations, Table VI details how each Grade 6 Natural Science topic was translated into a specific AR simulation format using CoSpaces Edu.

TABLE VI
AR SIMULATION DESIGN BY TOPIC AND FORMAT IN GRADE 6 NATURAL SCIENCE

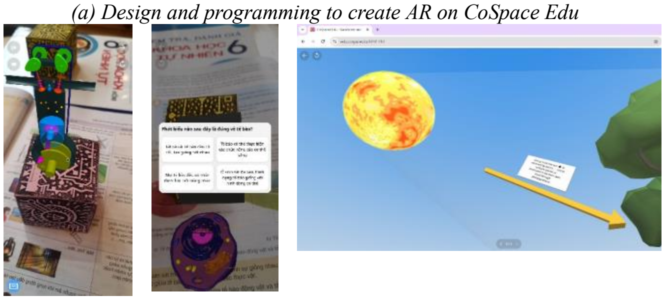
| Lesson/Topic | Simulation format | Purpose |
|---|---|---|
| Diversity of substances | Cube | Simulate states of matter (solid, liquid, gas). Each cubic side illustrates characteristic properties such as shape, density, expansion, … |
| | 3D model | The interaction of substance states allows users to switch between states and observe changes in properties. |
| Separate the substance from the mixture | Cube | The cubic sides describe methods of separating substances, such as filtration, distillation, and precipitation. Each side may contain an illustration of the principle and implementation steps. |
| | 3D model | The separation process helps students follow and better understand these processes. |
| Cell | Cube | Each cubic side represents a significant part of the cell: cell membrane, nucleus, mitochondria, chloroplast, … |
| | 3D model | Allows students to interact, zoom in/out, and explore the structure and function of parts. |
| Diverse living world | Cube | Each side depicts a different ecosystem (forest, sea, desert, etc.). Students can rotate the cube to compare and learn about the characteristics of each ecosystem. |
| | 3D model | 3D ecosystems and species models allow students to interact and observe their diversity. |
| Force | Cube | Each cubic side corresponds to a different type of force (push force, pull force, friction force, gravitational force, etc). |
| | 3D model | Simulate specific situations about the effects of force, such as pushing an object, pulling an object, the gravitational force acting on objects, etc. |
| Energy | Cube | Each face represents energy (heat, electricity, light, mechanical, chemical, etc.). Students can rotate the cube and observe energy conversion processes. |
| | 3D model | Simulate energy conversion processes, such as photosynthesis, fuel combustion, electricity production,… |
| Solar system | Cube | Each Cube's face represents a celestial body in the solar system (sun, planets, meteors, etc.). Students can rotate the Cube to observe celestial bodies and their relationships. |
| | 3D model | Simulate phenomena such as the day-night cycle, seasons,… Students can interact with the model and observe the laws of motion of the Solar System. |

## *C. Experimental Results and Discussion*

Fig. 3a illustrates the Cube design and 3D simulation using CoSpace Edu software. The program implements interactive programming for objects in the model, helping students. In addition to observing, students interacted directly with each component to better understand concepts, operations, processes, etc. Fig. 3b also introduces the students' experiences.



*(a) Design and programming to create AR on CoSpace Edu*



*(b) Student experiments*

Fig. 3. Illustration of design, programming to create AR on CoSpace Edu, and student experiments

Fig. 4 details the experimental group's evaluations across four core criteria: the level of lesson interest *(S.Q1)*, the role of 3D models *(S.Q2)*, active participation *(S.Q3)*, and their affinity for Natural Science *(S.Q4)*. The obtained data reflect a significant positive shift in students' learning attitudes following the AR technological intervention.

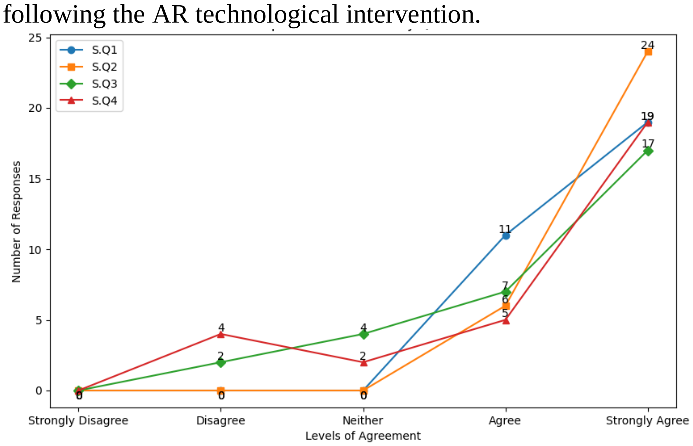



Fig. 4. Students' evaluation of using AR in Natural Science lessons

Regarding lesson appeal, up to 63.33% (19 students) strongly agreed that AR makes Natural Science lessons more engaging than traditional methods *(S.Q1)*. Notably, this figure rose to 80.00% (24 students) when specifically evaluating the role of 3D models in stimulating interest *(S.Q2)*. Qualitative feedback from the open-ended question *(S.QO1)* provided a clear explanation for these findings.

1. *Vivid, intuitive 3D models help me easily visualize abstract concepts.*
2. *I like to interact with and manipulate 3D models.*
3. *I think the AR technology is new and exciting, making me more curious about learning.*

Regarding engagement and subject affinity: The impact of AR transcended fleeting emotions, translating into tangible positive learning behaviors. Specifically, 93.33% (28 students) confirmed more proactive participation in learning activities *(S.Q3)*, and 86.66% (26 students) expressed a heightened interest in studying Natural Science *(S.Q4)*. This demonstrates that AR successfully fostered a highly interactive learning environment, where students transitioned from passive observers to active subjects in the process of knowledge construction. However, alongside the predominantly positive feedback, a minority of students expressed confusion and apprehension regarding the technology's effectiveness *(S.QO2)*.

1. *I need more experience to master this new technology.*
2. *I need support and answers to my questions when encountering difficulties during the experience.*
3. *The teacher should explain the functions and features of AR applications in more detail so I can get the most out of them.*
4. *The AR applications are designed to be simple and easy to use, so I don't waste time solving technical problems*
5. *I hope the school has a stable internet connection and can support devices for students with complex conditions to use AR.*

Students' positive responses to using AR technology in teaching and learning Natural Science facilitated the deployment of more AR technology applications in education.

To evaluate cognitive effectiveness and the ability to remember students' lessons when using/not using AR technology in 6th-grade Natural Science lessons, tests were conducted immediately after the course and after 2 weeks for both the experimental and control classes. Table VII shows the average score results of the tests at different times and the pass rate (scores of 8.0 or higher on the tests).

TABLE VII
SUMMARY OF AVERAGE SCORE IN 2 CLASSES

| Time | Experimental class | | Control class | |
|---|---|---|---|---|
| | Point average | Satisfactory rate | Point average | Satisfactory rate |
| After course | 8.2 | 87% | 7.5 | 66% |
| After 2 weeks | 7.8 | 75% | 6.7 | 57% |

According to the results, the experimental class's average score after completing the course was 8.2, corresponding to 0.7 points higher than the control class. Also, the rate of meeting requirements after completing the course was 87% in the experimental class, corresponding to 21% higher than the control class. In particular, after two weeks, the average score in the experimental class remained at 7.8, and the satisfactory rate was 75%. This result indicates that using AR technology in teaching Natural Science has brought positive cognitive effects to 6th-grade students compared to traditional methods. The experimental class's scores and pass rate were higher than the control class's, while students maintained learning efficiency and the ability to remember lessons better over time.

The study also used ANOVA analysis to determine whether the use of AR had a significant impact on student learning outcomes compared to traditional ones (Table VIII).

TABLE VIII
ONE-WAY ANOVA RESULTS FOR LEARNING OUTCOMES BETWEEN EXPERIMENTAL AND CONTROL GROUPS

| Source | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between groups | 6.765 | 1 | 6.765 | 12.190 | 0.001 |
| Within groups | 34.965 | 63 | 0.555 | | |
| Total | 41.730 | 64 | | | |

One-way ANOVA revealed a statistically significant difference in learning outcomes between the experimental and control groups ($F(1, 63) = 12.190$, $p = 0.001$). The effect size, calculated as eta squared, was $\eta^2 = 0.162$, indicating a large practical effect and suggesting that AR use accounted for approximately 16.2% of the variance in learning outcomes. These results provide strong evidence to reject the null hypothesis of no difference between groups.

These analyses are consistent with student survey information about AR interactions in Natural Science (Fig. 5). This technology helps students better understand complex concepts and processes *(S.Q5)*, explore and learn more deeply about topics *(S.Q6)*, focus more on lessons *(S.Q7)*, gain better knowledge *(S.Q8)*, and increase motivation to learn *(S.Q9)*.

Results indicate an absolute 100% of students confirmed that AR facilitates a clear understanding of scientific concepts and processes *(S.Q5)*. However, the level of deep understanding *(S.Q6)* reached 70.00% - a positive figure that nonetheless suggests the transition from 'visual clarity' to 'deep cognition' is a complex process requiring tighter integration between digital learning materials and teacher pedagogical coordination. Notably, 96.75% of students reported that AR significantly improved their knowledge retention *(S.Q8)*. This can be explained through Dual-Coding Theory: the synergy between verbal classroom instruction and interactive 3D imagery facilitates the creation of more durable memory traces.

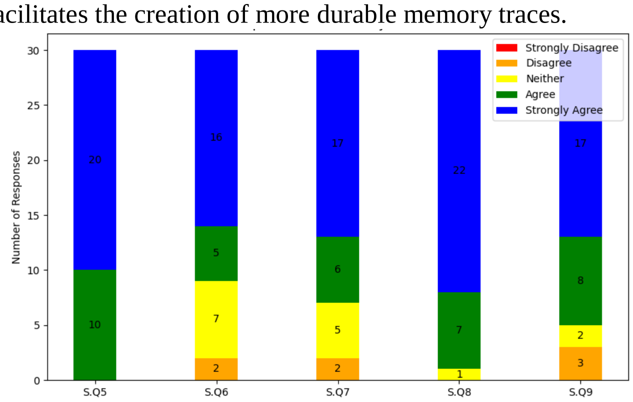



Fig. 5. Student survey results about AR interaction in Natural Science subjects

These findings are further consistent with constructivist learning principles, in which students construct understanding through active exploration rather than passive reception of information (Jonassen, 1994). The three-stage instructional model employed - pre-class preparation, in-class guided exploration, and post-class consolidation - reflects the concept of scaffolded learning, whereby teacher-mediated AR interaction supports students in bridging the gap between concrete visual experience and abstract conceptual understanding (Vygotsky & Cole, 1978). Taken together, these theoretical perspectives suggest that the effectiveness of AR in this study was not attributable solely to technological novelty, but rather to the pedagogical structure within which AR was embedded.

Furthermore, the ability to sustain focus *(S.Q7)* reached 76.66%, indicating that the AR environment fostered a more immersive learning space that effectively mitigated external distractions. Finally, the increase in learning motivation (*S.Q9***,** 83.33%) and the absolute consensus (100%) regarding the continued use of AR across other subjects (*S.Q10*) underscore the feasibility and potential value of broader implementation of this educational model, pending further validation across diverse school contexts.

Through integrating AR into teaching Natural Science, teachers have also had changes in awareness and realized some of the positive impacts of AR technology on students. However, teachers also found that using AR in teaching was relatively new and needed more time to perfect the skills. Besides, they gave some suggestions to enhance the performance of using AR in teaching Natural Science:

1. *Build a library of AR resources that is rich, diverse, and suitable for the curriculum content.*
2. *Organize training courses and guide teachers on skills to design and implement lessons using AR.*
3. *Encourage teachers to create and test new AR applications actively when teaching.*
4. *Improve technology infrastructure, such as equipping schools with computers, AR devices, and stable Internet connections.*
5. *Enhance coordination between relevant parties (schools, teachers, departments/departments of Education) to deploy AR in teaching effectively.*

Despite providing significant empirical evidence regarding the effectiveness of AR, we acknowledge that this study has certain limitations. First, the sample size was relatively modest, consisting of 65 students from a single secondary school, which may constrain the generalizability of the findings to the broader population of lower secondary students in Vietnam. Second, the research focused on specific content strands within the Grade 6 Natural Science curriculum, thus not fully encompassing the diversity of other topics within the 2018 General Education Program. Third, technological infrastructure barriers and teachers' digital competencies remain practical challenges that must be addressed to achieve a synchronized implementation of AR. Furthermore, potential confounding variables - including differences in individual teachers' instructional styles, students' baseline subject knowledge, and the extent of students' prior experience with AR-like technologies - were not fully controlled. Although both groups demonstrated comparable smartphone proficiency, more comprehensive baseline equivalence testing would strengthen the internal validity of future quasi-experimental designs in similar contexts. The formal psychometric validation of the student questionnaire, including confirmatory factor analysis and test-retest reliability, was also beyond the scope of the current study and is recommended for future instrument development. Additionally, the two-week delayed post-test, while providing initial evidence of short-term retention, does not capture longer-term knowledge consolidation. Studies with extended follow-up periods of one to three months would be needed to draw stronger conclusions about the sustainability of AR-supported learning gains.

In the future, research should aim to expand the sample size through multicenter studies and conduct longitudinal assessments to track knowledge retention over longer periods. Furthermore, developing a comprehensive library of AR learning resources and organizing specialized training programs to enhance teachers' design skills will be pivotal in optimizing the impact of this technology on educational quality.

## Conclusion

This study demonstrates that integrating AR technology via CoSpaces Edu into Grade 6 Natural Science instruction can meaningfully enhance both student engagement and academic performance. Three contributions emerge from the findings.

First, the experimental group consistently outperformed the control group on both immediate and two-week delayed post-tests. ANOVA confirmed statistically significant between-group differences ($p = 0.001$), and the effect size estimate ($\eta^2 = 0.162$) indicated a practically meaningful effect. The persistence of this advantage over the retention interval provides initial evidence that the observed gains reflect genuine learning rather than a transient novelty effect.

Second, the study proposed and validated a four-step AR integration process and a three-stage instructional model (pre-class, during-class, and post-class). Together, these frameworks offer educators a structured, replicable roadmap for embedding AR as an organic component of competency-based Natural Science instruction, rather than as an isolated visual aid.

Third, the successful development of AR learning materials across multiple Grade 6 topics using CoSpaces Edu - a platform requiring no advanced programming skills - demonstrates the practical feasibility of AR implementation within the infrastructure and digital competency constraints typical of Vietnamese lower secondary schools under the 2018 General Education Curriculum.

Several limitations should be noted. The modest sample size ($N = 65$) drawn from a single institution constrains the generalizability of these findings, and the quasi-experimental design limits causal inference. The two-week retention interval, while informative, does not capture longer-term knowledge consolidation. Future research should address these limitations through multi-school, multi-province designs with randomized or stratified assignment, longitudinal follow-up periods of one to three months, and formal psychometric validation of the student questionnaire beyond the acceptable internal consistency reported here ($\alpha = 0.793$). Expanding curriculum-aligned AR resource libraries and structured teacher professional development programmes will also be critical for sustainable, scalable implementation.

Overall, these findings contribute empirical and practical evidence to the growing body of research on technology-enhanced science education, with implications for AR integration in comparable educational contexts beyond Vietnam.

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