A Descriptive and Exploratory Study of an Augmented Reality Educational Product for Active Learning

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***Abstract*—This article presents an analytical discussion on the educational potential of *Explora*+, a digital educational product designed to enhance the teaching and learning of Science and Mathematics through Augmented Reality (AR). Adopting a qualitative and descriptive methodological approach, the study analyzes the product's structure, its pedagogical alignment with the Brazilian National Common Curricular Base (BNCC), and its effectiveness in exploratory classroom applications. The material integrates QR-code-based AR activities supported by mobile applications such as Arloopa, covering diverse topics including geometric solids, statistical graphs, the water cycle, cellular structures, virus reproduction, and human physiology. By merging curriculum-aligned content with interactive 3D models, *Explora*+ fosters conceptual understanding, student engagement, and the visual exploration of abstract concepts. The discussion is grounded in theoretical frameworks such as Mayer's Cognitive Theory of Multimedia Learning and Ausubel's Meaningful Learning, demonstrating how AR reduces extraneous cognitive load and anchors new knowledge through concrete visualization. Results from classroom observations and theoretical analysis indicate that AR significantly improves motivation, facilitates spatial reasoning through embodied cognition, and supports multimodal learning. We conclude that *Explora*+ represents an accessible, low-cost, and powerful resource for teachers seeking to integrate immersive technologies into basic education, thereby democratizing access to complex scientific visualization and promoting educational equity.**

***Keywords*—augmented reality, science, teaching, math**

I. Introduction

Digital technologies have profoundly transformed the landscape of contemporary education, reshaping teaching practices and expanding the ways in which students visualize, explore, and interact with scientific and mathematical concepts. In an increasingly digital society, schools are challenged to incorporate technological resources not merely as auxiliary tools, but as meaningful mediators of learning that promote engagement, conceptual understanding, and the development of higher-order cognitive skills. Within this context, immersive and interactive technologies have gained prominence for their potential to bridge the gap between abstract knowledge and concrete experience.

Among these technologies, Augmented Reality (AR) stands out as a particularly promising educational resource. By overlaying virtual elements onto the real physical environment, AR enables learners to interact with three-dimensional representations of objects, processes, and phenomena that are often difficult to observe or conceptualize through traditional instructional methods. Unlike static images or purely symbolic representations, AR fosters active exploration, allowing students to manipulate models, observe relationships from multiple perspectives, and construct knowledge through direct interaction. Such characteristics align with contemporary pedagogical approaches that emphasize active learning, multimodal cognition, and meaningful learning experiences [1].

In the field of Science and Mathematics education, AR has demonstrated strong potential to support the understanding of abstract and complex concepts, such as spatial geometry, molecular processes, and biological structures. Visualization plays a central role in these disciplines, and difficulties related to spatial reasoning, scale, and abstraction often hinder student learning. AR-based resources can mitigate these challenges by providing dynamic, interactive, and visually rich representations that reduce cognitive load and enhance conceptual clarity.

In this scenario, *Explora*+ was developed as an innovative pedagogical toolkit designed to support middle- and high-school education through the integration of AR into curriculum-aligned learning activities.

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Explora+ presents a collection of interdisciplinary resources articulated with curricular standards in mathematics, science, and biology, with particular attention to the competencies and skills defined by the Brazilian National Common Curricular Base (BNCC) [2]. The material seeks to transform commonly available mobile devices into learning tools, promoting accessible and low-cost technological integration in basic education.

Each *Explora*+ activity incorporates QR codes that activate three-dimensional animations and AR visualizations through mobile applications such as *Arloopa*. These resources enable students to explore a wide range of topics, including geometric solids (tetrahedron, dodecahedron, and icosahedron), statistical graphs, average speed, physical states of water, the hydrological cycle, cellular structures, meiosis, viral reproduction, digestion, gestation, and blood coagulation. By combining printed or digital instructional material with interactive AR content, *Explora*+ encourages exploratory learning, student autonomy, and active participation in the construction of knowledge.

Thus, *Explora*+ positions itself as a pedagogical product that responds to contemporary educational demands by integrating digital culture, curriculum alignment, and active learning methodologies. Its design reflects the growing need for educational resources that not only incorporate technology but also do so in a pedagogically grounded manner, fostering engagement, inclusivity, and meaningful learning in Science and Mathematics education.

The objective of this article is to demonstrate the pedagogical potential of *Explora*+, analyzing its contribution to the understanding of abstract concepts and discussing the advantages of AR-mediated learning. We also highlight how AR applications can support active learning, multimodal cognition, and meaningful engagement in Science and Mathematics classrooms.

II. Literature Review

A. Augmented Reality as an Immersive Technology in Education

Contemporary education is undergoing a period of rapid technological innovation, profoundly transforming teaching methodologies and knowledge acquisition processes [2]. In this scenario, AR becomes a pedagogical tool with high potential.

Recent works, such as Ferreira and Botelho [3], highlight that AR acts as an innovative approach in science teaching. It allows educators to overcome the limitations of traditional methods by superimposing informative virtual elements onto the real physical environment. Unlike Virtual Reality, which isolates the user, AR enriches the perception of reality. This characteristic is fundamental to promoting what Rocha *et al*. [4] identify as active and playful methodologies. These are essential for student engagement, like how mathematical games are used in diverse educational contexts, as shown in Fig. 1.

Interactivity alters the student's cognitive relationship with the object of study, promoting greater autonomy and transforming the classroom into a space for experimentation.

Fig 1. Difference between the use of augmented reality and virtual reality.

Systematic literature reviews emphasize that the use of immersive technologies favors the transition from passive teaching to active learning approaches [5, 6]. When using AR, the student ceases to be a spectator of static information and becomes an exploring agent.

The *Explora*+ product utilizes this premise by providing ready-made activities where mobile devices become windows for visualizing visual concepts. This interactivity alters the cognitive relationship of the student with the object of study, promoting greater autonomy and engagement [7].

Furthermore, intrinsic motivation is widely benefited by the adoption of AR. The insertion of visual elements, such as manipulable 3D models, captures students' attention differently than traditional expository methods. This curiosity sparked by technology results in more effective participation and lasting knowledge retention, transforming the classroom into a space for scientific experimentation [6].

B. Interdisciplinary Practices and Meaningful Learning

The complexity of modern curricula requires tools that facilitate the understanding of phenomena through multiple disciplinary lenses. In Mathematics teaching, specifically in Spatial Geometry, the visualization of three-dimensional forms is a constant challenge. Oliveira *et al*. [8] demonstrate that the use of solids in Augmented Reality (AR Solids) functions as a powerful tool not only for regular teaching but also as an instrument of school inclusion, facilitating the understanding of geometric properties by students with different learning needs.

This visual approach is corroborated by the need to mitigate negative impacts on the quality of teaching. Studies on the impacts of visual alterations on student performance suggest that the quality of visual resources used in the classroom directly influences content retention [8]. Thus, tools like *Explora*+, by offering clear and manipulable models of polyhedra and biological structures, meet this demand for cognitive and visual ergonomics, facilitating the construction of accurate mental models [9].

The pedagogical efficacy of AR use can be grounded in Richard Mayer's Cognitive Theory of Multimedia

Learning. AR acts at this convergence point, combining verbal instruction (text/audio) with 3D visual representation, which reduces extraneous cognitive load and expands the student's processing capacity.

Additionally, the tool aligns with the principles of David Ausubel's Meaningful Learning. For Ausubel [10], learning occurs when new knowledge anchors itself in prior concepts (subsumes) within the student's cognitive structure. The concrete visualization provided by AR serves as a powerful "advance organizer", transforming arbitrary concepts into representations with logical meaning. For example, visualizing molecular change during evaporation anchors the theoretical concept in a concrete experience, aiding conceptual change.

Studies on "embodied cognition" also reinforce that the motor act of manipulating the device to explore the virtual object strengthens memory and spatial reasoning, making learning a multimodal experience [11].

C. Alignment with the BNCC and Digital Culture

Technological integration must align with the BNCC's guidelines for equity and inclusion. "Digital Culture", the 5th general competency of the BNCC, is not limited to the instrumental use of technology, but extends to its critical and inclusive use [2].

Oliveira *et al.* [8] highlight the role of AR Solids as an inclusion tool for students with visual impairments or difficulties in spatial abstraction, democratizing access to complex geometric knowledge. The use of accessible mobile technologies enables the application of these tools in public schools, supporting the ideal of quality education for all. Furthermore, the diversification of strategies, such as the use of games and interactivity discussed by Rocha *et al.* [4], ensures that different student profiles are contemplated, respecting the cognitive and visual specificities of each learner in the teaching-learning process.

Fig. 2 illustrates how the BNCC framework connects digital literacy and mobile learning, curriculum alignment with learning goals, and equity and accessibility, highlighting its role in guiding inclusive and technology-integrated education.

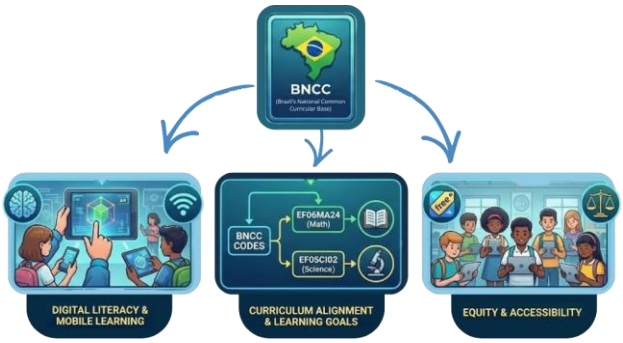

Fig. 2. Explanation of AR use according to the BNCC.

Thus, the application of AR in the classroom directly addresses this competency, promoting digital literacy and transforming mobile devices into learning tools [2]. The mapping of activities with BNCC codes (such as EF06MA24 and EF05CI02) evidences the commitment to learning objectives, ensuring that technology serves the curriculum. Moreover, the accessibility of free applications democratizes access to cutting-edge resources, making their application in public schools feasible and supporting the ideal of educational equity.

III. Materials and Methods

A Fig. 3 presents the methodological procedure of the study, organized into four phases—product analysis, pedagogical alignment, exploratory application, and evaluation of potentialities—highlighting the steps used to examine the AR activities, their curricular alignment with BNCC competencies, their classroom implementation, and their educational contributions.

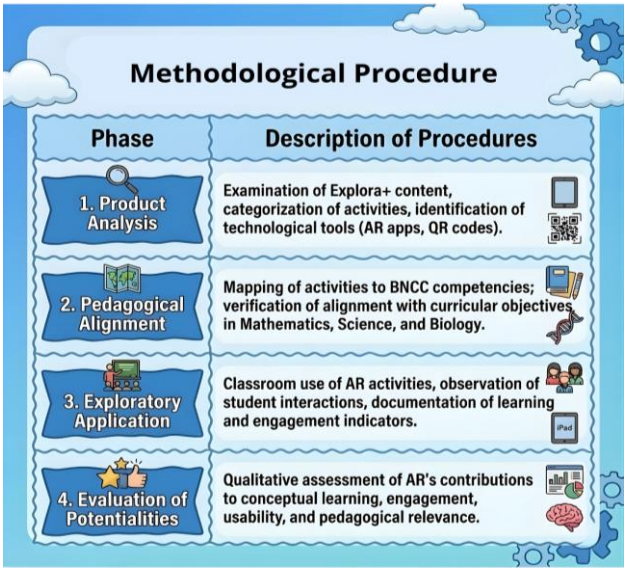

Fig. 3. Step-by-step methodological procedure.

Furthermore, this study employed a qualitative, applied, and descriptive methodological approach to analyze the educational potential of *Explora+*, a digital product that integrates Augmented Reality (AR) into the teaching of Science and Mathematics. The methodological design was structured into four phases: (1) product analysis, (2) pedagogical alignment, (3) classroom-based exploratory application, and (4) evaluation of potentialities. Each phase is described in detail below.

A. Product Structure and Content Analysis

The first phase consisted of an in-depth examination of the *Explora+* material, including its set of AR activities, curricular alignment, QR code functionality, and the mobile applications required for interaction (primarily Arloopa and Easy AR). All activities were classified according to the thematic areas of Mathematics, Science, and Biology, considering their level of conceptual complexity and the type of AR visualization provided.

B. Pedagogical Alignment with Curricular Standards

The second phase involved analyzing how the content and activities correspond to competencies and skills defined in the Base Nacional Comum

Curricular—National Common Curricular Base (BNCC). This phase ensured that the product's activities—such as geometric solids, average speed, water cycle, cellular structures, and viral reproduction—align with expected learning outcomes for middle school students. Brazilian curricular codes (e.g., EF06MA24, EF07MA36, EF05CI02) were mapped to the AR activities to validate curricular consistency.

C. Exploratory Classroom Application

In the third phase, selected activities from *Explora+* were tested in real or simulated classroom scenarios to observe student engagement, interaction patterns, and conceptual understanding. Students used mobile devices to scan QR codes embedded in the PDF, visualizing AR models [12]. This phase aimed to document:

- Behavioral indicators of engagement (e.g., curiosity, interaction frequency, collaborative exploration).
- Cognitive indicators (e.g., ability to describe geometrical properties after manipulating solids, understanding of the water cycle, recognition of cellular organelles).
- Challenges and opportunities (e.g., digital access, usability, classroom management).

Observations and informal feedback from students and teachers supported the evaluative process.

D. Evaluation of Educational Potentialities

The final phase focused on analyzing the capabilities of AR-based learning as provided by *Explora+*. The evaluation considered four criteria [13]:

(1) Visualization capacity—how AR improves the comprehension of abstract concepts.
(2) Curricular relevance—alignment with BNCC skills.
(3) Student engagement—motivational effects observed during activities.
(4) Technological accessibility—ease of use, device compatibility, and implementation feasibility in public-school contexts.

These criteria were assessed qualitatively through comparative analysis with findings from the scientific literature on AR in education. The observed characteristics of *Explora+* were contrasted with theoretical and empirical evidence reported in previous studies, allowing for a critical examination of its educational potential. This comparative approach enabled the identification of convergences between the design principles of *Explora+* and well-established frameworks in AR-based learning, particularly those related to visualization, cognitive engagement, and curriculum integration.

In addition, the analysis sought to understand how the combined evaluation criteria interact to support meaningful and active learning experiences. Visualization capacity and curricular relevance were examined not as isolated dimensions, but as complementary factors that ensure pedagogical coherence between technological resources and learning objectives. Student engagement was analyzed as both a motivational outcome and a mediating variable in knowledge construction, while technological accessibility was considered essential for scalability and equity in public-school settings. Together, these dimensions provide a comprehensive framework for evaluating AR-based educational products, highlighting *Explora+* as a viable and pedagogically grounded resource for integrating immersive technologies into basic education.

IV. Result and Discussion

A. Visual and Spatial Learning in Mathematics

One of the central strengths of *Explora+* is its capacity to convert abstract mathematical concepts into tangible visual experiences. With AR-enabled activities, students can manipulate geometric solids such as the tetrahedron, dodecahedron, and icosahedron, observing the arrangement of faces, edges, and vertices in real time. This dynamic visualization supports spatial reasoning, a critical competency in geometry education.

The statistical-graphics activities also benefit from AR by allowing learners to explore bar graphs and percentages in a more intuitive manner, supporting competencies from the BNCC indicators such as EF07MA36. Research shows that AR enhances mathematical reasoning by linking symbolic representations to concrete models, reducing cognitive load and facilitating comprehension.

B. Enhancing Conceptual Understanding in Sciences

In the Sciences component, *Explora+* integrates AR models that depict the water cycle, the physical states of water, and processes such as condensation, evaporation, and precipitation. These visualizations align with BNCC competencies EF04CI03 and EF05CI02 and help students understand phenomena that are often difficult to observe directly.

Students can compare molecular behavior in the solid, liquid, and gaseous states as animated particles change their arrangement and movement patterns in AR space. This type of embodied cognition improves retention and supports conceptual change, particularly when dealing with misconceptions about phase transitions.

C. Biological Processes through Immersive Interaction

Biology content represents one of the most impactful uses of AR within *Explora+*. Complex structures such as plant cells, virus replication cycles (lytic and lysogenic), human digestive organs, and meiosis stages are presented as manipulable 3D models. This is especially beneficial for abstract biological processes that require visualization beyond traditional textbook images.

For example, the AR-based meiosis model allows learners to follow chromosome behavior through prophase, metaphase, anaphase, and telophase, reinforcing understanding of genetic variability and gamete formation. Studies in biology education demonstrate that AR reduces cognitive barriers and improves comprehension of microscopic structures [11].

D. Student Motivation

Across all disciplines, the use of AR significantly increases student motivation. The interactive nature of *Explora+* transforms the learning environment into an exploratory experience, encouraging curiosity,

experimentation, and problem-solving. Students report greater motivation and confidence when interacting with AR elements, which corresponds with findings in contemporary educational research on immersive technologies.

Teachers also benefit, as AR tools facilitate differentiated instruction, support visual learners, and provide opportunities for collaborative activities. The ability to integrate mobile devices—already familiar to students—reduces technical barriers and promotes seamless adoption in the classroom.

E. Accessibility and Educational Integration

A notable characteristic of *Explora+* is its accessibility: it uses free applications, low-cost technology, and simple QR codes, making it suitable for public-school environments. Additionally, the product is aligned with national curricular standards and provides a cross-disciplinary structure that supports integrated learning.

This adaptability positions *Explora+* as a scalable model for other digital educational products, demonstrating how AR can be integrated into schools without expensive infrastructure or specialized equipment.

V. Conclusion

Explora+ demonstrates strong potential as an educational product that enhances the teaching and learning of Science and Mathematics by integrating Augmented Reality into curriculum-aligned activities. AR-based visualization aids in conceptual understanding, improves spatial reasoning, and transforms abstract ideas into interactive experiences. The interdisciplinary nature of the product enables its application in numerous pedagogical contexts, strengthening connections between scientific concepts.

The analysis presented here supports the conclusion that AR technologies, particularly those implemented through accessible mobile applications, offer significant benefits for student engagement, motivation, and conceptual comprehension in Science and Mathematics education. By enabling interactive visualization of abstract and complex phenomena, AR contributes to the development of spatial reasoning, supports multimodal learning processes, and reduces cognitive barriers commonly associated with traditional instructional approaches.

Within this context, *Explora+* emerges as a valuable and pedagogically grounded educational product, capable of integrating immersive technologies into curriculum-aligned classroom practices. Its alignment with the BNCC, combined with its interdisciplinary structure and low-cost technological requirements, reinforces its potential for application in public-school settings. Furthermore, the use of QR codes and freely available mobile applications facilitates ease of implementation and scalability, allowing teachers to incorporate AR into their instructional routines without the need for specialized infrastructure.

From a pedagogical perspective, *Explora+* promotes active and exploratory learning by positioning students as active participants in the construction of knowledge. The observed motivational effects and levels of engagement suggest that AR-mediated activities can foster curiosity, autonomy, and collaborative learning, contributing to more meaningful educational experiences. In addition, the product supports differentiated instruction by addressing diverse learning styles and facilitating the understanding of content that relies heavily on visualization.

Finally, this descriptive and exploratory study highlights the relevance of AR-based educational products as strategic resources for innovation in basic education. While the present analysis focused on qualitative indicators of educational potential, future research may include empirical investigations with larger samples, quantitative assessments of learning outcomes, and longitudinal studies to evaluate long-term impacts on student achievement. Such studies may further consolidate the role of AR as a transformative tool in education and expand the possibilities for the development of inclusive, engaging, and curriculum-aligned digital learning resources.

The results indicate that the pedagogical use of Augmented Reality in *Explora+* enhances conceptual understanding and student engagement, findings that are consistent with Mayer's Cognitive Theory of Multimedia Learning, as the integration of verbal information with interactive three-dimensional visual representations reduces extraneous cognitive load and supports meaningful learning.

Future work may include empirical classroom studies, long-term assessments of learning gains, and expansion of the AR content to additional STEM topics.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Welberth S. Ferreira wrote the paper and conducted the research. Iury T. D. Botelho combed the literature and Suelen R. B. Ferreira revised the manuscript. Elyzabelle. P. C. Vasconcelos and Keyne. C. M. Silva prepared the figures for the article, while Antonio. N. L. Silva conducted the analysis and refinement of the qualitative data. All authors had approved the final version.

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