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INTERACTIVE VIRTUAL ENVIRONMENT FOR SECONDARY SCHOOLS: APPLYING VIRTUAL REALITY TO THE TEACHING-LEARNING PROCESS

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Final Course Project submitted to the Institute of Technology and Leadership (INTELI), to obtain a bachelor's degree in Software Engineering.

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ABSTRACT

This work investigates the design and development of an immersive educational solution using Virtual Reality (VR) and Augmented Reality (AR) to support learning in Brazilian high school contexts, in partnership with MIRAI, a company specialized in customized educational technology experiences. The study aims to (i) justify the business and pedagogical relevance of immersive technologies for secondary education, (ii) define a technically viable architecture aligned with corporate constraints, and (iii) validate the feasibility of implementing a prototype using the Godot Engine as the core XR development platform. The research is grounded on educational theories that emphasize learner protagonism and active methodologies, as well as national curriculum guidelines that reinforce digital culture competencies. From a technological perspective, the solution adopts an integrated approach combining a Godot-based XR application with a cloud-oriented backend, emphasizing scalability and maintainability through modern paradigms such as serverless architecture, standardized asset formats (e.g., glTF), and device interoperability via OpenXR. The development process follows agile principles supported by DevOps practices and project management standards inspired by PMBOK to ensure iterative delivery, risk control, and stakeholder alignment. As outcomes, the work consolidates a structured rationale for adopting VR/AR in high school education, demonstrates the technical suitability of Godot for cost-efficient and multi-device XR deployment, and establishes a methodological framework for future pilot deployments and impact assessment in educational environments. The conclusions indicate that immersive learning solutions can enhance engagement and conceptual understanding when integrated with clear pedagogical goals, while highlighting practical limitations related to infrastructure, teacher training, and content production that must be addressed for scalable adoption.

Key words: immersive learning; virtual reality; augmented reality; Godot Engine; secondary education.

Summary

1 Introduction

We are living in an era marked by significant technological advances, which have profoundly transformed various aspects of society, including the educational field. The growing integration of technology into people's daily lives requires us to reflect on the possibilities of its application in the teaching-learning process, especially regarding the potential improvement of traditional methodologies used in the classroom. This transformation aims not only to optimize the teacher's pedagogical practices but also to promote student engagement and motivation in relation to the curricular content established by the Brazilian National Common Curricular Base (BNCC). Various theorists, such as Freire (1996), have long advocated overcoming a banking, traditional, and passive education model, proposing instead a student centered approach based on dialogue, active participation, and the stimulation of knowledge construction.

In this context, it is observed that purely traditional teaching methods no longer effectively meet contemporary educational demands. This is where the concept of Active Learning emerges, proposing student-centered pedagogical strategies that emphasize problem solving, hypothesis formulation, and active participation in the construction of knowledge (ROCHA; LEMOS, 2014).

This demand for new educational strategies has paved the way for innovative approaches capable of making the teaching-learning process more dynamic and appealing to students. These approaches involve the integration of technological resources that support the transformation of pedagogical practices, enabling new forms of interaction and knowledge building. Among these resources, Virtual Reality (VR) and Augmented Reality (AR) stand out.

Virtual Reality is an advanced interface for computer applications that allows users to navigate and interact in real time within a three-dimensional environment, often using multisensory devices for action or feedback (Tori, Kirner, and Siscoutto, 2006). This technology enables interactive and immersive representations of both imaginary scenarios and real-world reproductions, facilitating user engagement in a 3D space. In addition to conventional interaction via menus or buttons, VR allows individuals to directly manipulate three-dimensional elements, enhancing their perceptual and sensory capabilities in both time and space. Through 3D modeling, virtual objects and scenarios are developed, enabling a richer and more immersive navigation experience.

The advancement of multimedia technologies and Virtual Reality has been driven by the increasing processing power of computers, allowing real-time integration between videos and interactive virtual environments. Augmented Reality, in turn, has directly benefited from these advances by enabling the overlay of virtual elements onto the physical environment, expanding its potential applications in various contexts. Its use has become feasible not only on sophisticated platforms but also on accessible devices such as smartphones, democratizing its reach. Unlike Virtual Reality, which completely replaces the real environment with a simulated one, Augmented Reality inserts virtual objects into the user's physical space, fostering a more fluid, intuitive, and accessible interaction experience—often eliminating the need for training or complex equipment (TORI; KIRNER; SISCOUTTO, 2006). Studies such as that by Macedo and Fernandes (2015) highlight that the use of AR in educational contexts provides advantages such as 3D visualization of experiments, opportunities for students to interact with content, and simplicity in the use of the technology, making it a viable and efficient learning tool.

Considering, therefore, the continuous evolution of technological resources and the need for more effective and engaging teaching methodologies, this study analyzes the use of Augmented Reality and Virtual Reality as innovative and promising tools to enhance classroom learning. These digital and interactive technologies are becoming established as important pedagogical resources, not only for the benefits they offer to the teaching-learning process but also due to the urgent need to align educational practices with the technological transformations shaping the contemporary world.

1.1. **Partner Company Context**

MIRAI operates within the educational technology (EdTech) sector, directing its activities toward innovation in teaching through technology. EdTechs, in general, are companies or startups that employ technological resources to transform education, offering solutions ranging from online learning platforms and personalized learning to augmented reality (AR) tools and gamification. By incorporating innovations such as artificial intelligence and AR, these companies seek to enhance the teaching experience and increase student engagement. The central objective of EdTechs is to reinvent learning methods and revolutionize educational processes through technology, thereby overcoming the traditional model of instruction. In this context, MIRAI was created precisely with the purpose of generating a positive impact on the use of technologies to support the educational process, operating as both a consultancy and a developer of customized teaching experiences. In other words, the company develops tailor-made solutions to help educators improve the teaching process and the transmission of knowledge, aligning itself with the trend of placing technology at the service of pedagogy in order to achieve better learning outcomes.

From the standpoint of organizational size, MIRAI can be characterized as a small- to medium-sized company, typical of a technology-based startup focused on education. The educational startup ecosystem is experiencing significant growth in Brazil and worldwide, encompassing companies of MIRAI's size. In Brazil alone, there were more than 500 active EdTechs in 2024, a figure that consolidated the country's position as a leader in educational innovation in Latin America. Founded within this dynamic landscape, MIRAI represents one of these innovative organizations that have emerged to meet the demand for technological solutions in basic and corporate education. Its lean and highly specialized structure allows for agility in the implementation of new ideas, a common characteristic of small companies in the EdTech sector. Thus, MIRAI's field of operation is educational consultancy and technology development applied to education, while its size corresponds to that of a small innovative enterprise—facilitating a focus on specific niches (such as secondary education, in the case of this project) and rapid adaptation to emerging trends in education. It is worth noting that the global EdTech market projects increasing investments in cutting-edge educational technologies; for example, spending on AR and virtual reality (VR) in education is estimated to reach USD 12.6 billion in 2025, a figure that is nearly double the projected investment in artificial intelligence within the sector. These data reinforce that companies such as MIRAI, operating in educational technology, are positioned within a strategic and expanding segment, in which continuous innovation is a critical success factor.

The virtual and augmented reality project applied to secondary education directly impacts MIRAI's core area of educational solution development, specifically the unit focused on creating innovative learning experiences within the context of basic education. In an organization oriented toward educational innovation such as MIRAI, there are no rigid distinctions between technology and pedagogy; therefore, the project will involve an interdisciplinary approach, engaging both the technology/software development department and the organization's pedagogical team. This educational innovation core is responsible for conceiving and implementing customized teaching experiences and will be profoundly influenced by the incorporation of AR/VR into its processes.

More concretely, the AR/VR initiative for secondary education will affect the way MIRAI designs instructional materials and training programs for educators working at this level of education. The company operates by providing consultancy services to schools and teachers, which suggests that its educational consultancy department (responsible for implementing solutions in partner educational institutions) will also be impacted. This department will need to adapt its teacher training methodologies to include the effective use of virtual and augmented reality tools in the classroom. In parallel, MIRAI's technological development team—possibly functioning as an educational R&D laboratory—will have its scope of work expanded to encompass the design and programming of immersive virtual environments aligned with secondary school curricula. Thus, the project touches central areas of the company: from the creation of pedagogical content enriched with immersive technology to the training of teachers and students to use these tools. In sum, the department (or functional area) most directly impacted is the one responsible for developing innovative educational experiences—which, within MIRAI's structure, integrates pedagogical and technological competencies—since it is within this area that the AR/VR solution will be conceived, prototyped, and refined before being delivered to end users (secondary school teachers and students).

MIRAI's decision to support a virtual and augmented reality project focused on secondary education is grounded in several strategic factors, all converging toward the strengthening of its mission of educational innovation. First, there is an imperative of technological leadership: AR and VR have emerged as some of the leading trends in education, offering immersive learning experiences that can shape new ways of teaching. The global education sector has increasingly adopted these technologies in recent years, recognizing their potential to revolutionize pedagogical practices. For MIRAI, active engagement with AR/VR means aligning itself with these cutting-edge trends, ensuring that the company remains competitive and relevant in a market where constant innovation is highly valued. Supporting the present project enables the company to develop internal expertise in immersive technologies and to generate a demonstrable success case, factors that may differentiate it in the eyes of clients (schools and education networks) seeking modern solutions. Indeed, the successful incorporation of AR/VR into basic education would position MIRAI as a reference in technology-mediated active methodologies, creating brand value and intellectual leadership within the educational EdTech niche.

Second, the strategic motivation also derives from the proven pedagogical benefits that AR and VR can bring, particularly in secondary education. Research and practical experiences indicate that AR/VR tools significantly increase student engagement and motivation, facilitating the learning of complex concepts through visualization and interaction. In the context of secondary education—an educational stage in which student disengagement with traditional methods is often observed—the use of immersive virtual environments can transform the abstract into the concrete, allowing students to interact with 3D objects, simulate scientific phenomena, or “travel” to historically relevant scenarios aligned with the curriculum. For example, through VR, a student can explore a virtual replica of Ancient Egypt or conduct a chemistry experiment in a virtual laboratory without real-world risks, experiencing in practice content from History or Natural Sciences. This type of experience provides deep experiential learning, which is difficult to achieve through lecture-based instruction alone, and aligns with the most effective practices in contemporary instructional design (learning based on experience and experimentation). Strategically, MIRAI recognizes value in supporting a project that demonstrates these advantages in practice, as the results may underpin the expansion of its product and service offerings. By mastering the use of AR/VR in secondary education, the company can offer the educational market high-impact innovative solutions, meeting a growing demand for engaging educational technologies. Moreover, involvement in this project allows MIRAI to closely monitor the pedagogical implementation of the technology, obtaining valuable data and insights regarding effectiveness, engagement, and usability, which will inform future strategic decisions and the development of new projects. In sum, the company's support is motivated by the convergence of an opportunity for disruptive innovation—with high potential to improve the teaching–learning process—and the competitive advantage of being among the pioneers in applying AR/VR in Brazilian basic education.

The AR/VR project applied to secondary education directly aligns with MIRAI's fundamental objectives as an organization dedicated to educational innovation. Since its founding, MIRAI has defined as its central purpose "to generate impact through the use of technology to support the educational process," acting to assist educators in improving teaching practices and the transmission of knowledge. This strategic orientation is materialized in the provision of customized and technologically enriched teaching experiences, precisely what the present project seeks to achieve. Virtual and augmented reality represent, in this case, tools capable of enhancing the teaching process, making it more efficient and better aligned with the needs of the current generation of students. By enabling more interactive and engaging classes, the project promotes active learning, in which students assume a protagonistic role—approaches of this nature foster greater student engagement and deeper intellectual connections with content. Such educational outcomes (greater engagement, personalization, and teaching effectiveness) lie at the core of MIRAI's vision, which seeks precisely to transform education through innovative methodologies.

Furthermore, the personalization and customization offered by the project—by creating AR/VR experiences adapted to the secondary school curriculum—reflect the company's philosophy that educational solutions should be shaped according to context and audience. MIRAI, as a consultancy and developer of educational experiences, aims to support each institution and teacher in a unique manner; the application of AR/VR enables complex content to be adapted to the visual and interactive language that resonates with young learners, addressing the new pedagogical demands of the digital era. In this way, the project proposal acts as a natural extension of MIRAI's objectives: it demonstrates in practice how cutting-edge technology can empower teachers and enrich the teaching process, generating the positive impact sought by the company. Strategically, the project serves as proof of concept for MIRAI's mission—that is, it provides evidence that well-applied technological innovation can significantly improve basic education. By supporting and co-developing this initiative, MIRAI not only fulfills its institutional mission but also strengthens its long-term objectives, which include leading digital transformation in education and consolidating itself as a reference in educational innovation. In sum, there is complete alignment between the proposed project and MIRAI's organizational objectives: both converge toward innovating the pedagogical process, enhancing the quality of education through the creative and effective use of technology, to the benefit of secondary school teachers and students.

1.2. **Problem Definition**

In recent decades, education has faced significant challenges, particularly with regard to student engagement. As highlighted by Pozo (2002), one of the main obstacles encountered by educators is the lack of interest and motivation among students—a factor that directly compromises the teaching-learning process. Motivation, according to the author, is associated with psychological processes that influence student behavior in learning situations, and is therefore an essential element to be considered in pedagogical practice. Traditional methods, mostly developed in pre-digital contexts, have increasingly proven insufficient to meet the pedagogical demands of a generation that is growing up immersed in digital technologies (PRENSKY, 2001). This gap between teaching practices and student expectations contributes to demotivation and the consequent decline in academic performance.

Moreover, the Brazilian National Common Curricular Base emphasizes the importance of adopting methodologies that foster the development of socio-emotional competencies and practical skills—aspects that are often not fully addressed in traditional teaching approaches.

Although the benefits of using educational technologies are widely recognized, their implementation in Brazilian school contexts is still at an early stage. Personalized learning, for example, has shown promise, but its implementation faces structural limitations, requiring from teachers not only technical proficiency but also additional time and dedication to identify and address the individual needs of their students (PETERSON et al., 2018). In light of this, several guiding questions arise:

a) How can the creation of interactive virtual environments based on VR and AR impact the teaching-learning process in the context of high school education? With an emphasis on enhancing didactic materials and promoting more engaging methodologies aligned with the technological and pedagogical transformations of the 21st century.
b) What existing applications of VR and AR in education, and what have their outcomes been?
c) Which subjects present greater feasibility for the implementation of these technologies? Are virtual and augmented reality applicable to all areas of knowledge?
d) How do students and teachers perceive and accept the adoption of new tools that complement traditional teaching, especially in subjects that require visual and experiential learning?
e) Do educational institutions have the necessary human, technical, and financial resources to support the implementation and maintenance of VR and AR-based platforms?

1.3. Proposed Solution and Expected Contribution

- Presentation of the proposed computational solution;
- **Contribution Objective: What is the** *quantifiable* result that the project should deliver? (Ex : Reduce time by X%, Increase accuracy by Z percentage points.)

1.4. Business Objectives

In view of the foregoing, the project objectives were delineated from the perspective of the partner company MIRAI, that is, the expected outcomes that the proposed solution should deliver to the business and to its clients in the educational sector. In general terms, the project is expected to contribute to the following results for the company:

a) Pedagogical Innovation within the Portfolio: Development of a functional prototype of an educational platform based on VR/AR, expanding MIRAI's product portfolio with an innovative solution that transforms curricular content into immersive experiences. It is expected that this innovation will make the company's solutions more attractive to schools and education networks seeking to incorporate cutting-edge technologies aligned with the BNCC and with active learning methodologies.
b) Increased Engagement and Effectiveness: Demonstration, through pilot studies or controlled tests, that the use of VR/AR in secondary education increases student engagement and can improve the understanding of complex content when compared to traditional methods. This outcome would provide MIRAI with concrete evidence (data and pedagogical feedback) of the solution's added value, serving as a proof of concept for future implementations on a commercial scale.
c) Customization and Curricular Adaptation: Delivery of a flexible solution, built on the Godot engine, that enables the creation and customization of different immersive educational modules (for example, a virtual science laboratory, an augmented reality visit to a historical site, etc.). This will address the need for frequent customization in MIRAI's solutions, making it possible to adapt the product to the specific demands of each partner educational institution, without reliance on costly licenses or complex infrastructures.
d) Technological Capacity Building and Market Differentiation: Training MIRAI's team in the mastery of new technologies (Godot, VR/AR frameworks, serverless architecture, etc.), strengthening the company's human capital in immersive development competencies. The know-how acquired throughout the project is expected to position MIRAI in a differentiated manner within the EdTech market, enabling it to offer immersive educational solutions competitively and on a proprietary basis (through the use of open-source tools, thereby avoiding licensing costs). It is expected that this will create competitive advantage and potential for new business opportunities, given that the VR/AR market in education is undergoing rapid global expansion.

In summary, the project objectives reconcile academic research on the use of VR/AR in education with the generation of practical value for the partner company. Achieving these objectives will signify not only the fulfillment of a curricular requirement (the completion of the undergraduate thesis), but also the delivery to MIRAI of a solution and a body of knowledge applicable to its operational context, thereby contributing to its mission of innovating teaching–learning processes through technology.

1.5. **Structure of the thesis/dissertation:**

This undergraduate thesis report is organized into chapters that reflect the logical progression of the research, ranging from theoretical foundations to practical application and conclusions. The following presents an overview of the contents of each chapter:

Introduction and Justification: (the present chapter) Provides contextualization of the topic, outlines the relevance of the use of VR/AR in secondary education, presents the partnership with the company MIRAI, defines the project objectives from a business perspective, and describes the overall structure of the study.

Foundations and Applied Justification: Brings together the theoretical and practical framework that underpins the project. Relevant concepts from the educational sector of the partner company are detailed (educational business context and trends in the use of VR/AR in teaching), as well as the technological rationale of the solution (technologies involved, development methodologies considered, and justification for the choice of the Godot engine). The foundations of project management and development methodologies adopted in the corporate environment to enable the implementation of the proposed solution are also reviewed.

Methodology: Describes the methodological procedures adopted in the development of the project. It encompasses the stages of research and requirements elicitation, system planning (including the proposed architecture, data models, etc.), the technologies and tools used, and the manner in which the project was conducted in interaction with the partner company (for example, the use of agile methodologies, development sprints, and continuous validation with stakeholders).

Development and Results: Presents the practical application of the project. It details the implementation of the VR/AR solution, including the integration of components (content authoring front end, serverless backend architecture, Godot-based VR application, etc.). The main functionalities developed are described and illustrated with examples (e.g., a pilot VR-based chemistry teaching experience—construction of a virtual laboratory to explore molecular models). This chapter also discusses the results obtained, both in terms of technical performance and in terms of a preliminary evaluation of the user experience by educators and students involved in the tests.

With this structure, it is expected to provide the reader with a comprehensive understanding of the project—from the why (theoretical, educational, and business justifications), through the what (the proposed solution and technological foundations) and the how (methods and development), and ultimately arriving at the so what? (the results obtained and final reflections).

2 Solution Development

Integrating immersive technologies into the school environment requires grounding from educational, technological, and organizational perspectives. This chapter presents the theoretical and practical foundations that justify the adoption of VR/AR in the context of secondary education, aligned with the business needs of the partner company MIRAI. Initially, the rationale applied to the educational business domain is examined, addressing relevant pedagogical concepts and market best practices in the use of VR/AR in the classroom. Subsequently, the technological rationale is explored, reviewing the technologies and methodologies involved (such as modern software architectures and development paradigms) and providing a technical justification for the choice of the Godot engine for the implementation of the solution at MIRAI. Finally, the foundations of the project management and development methods employed are discussed—for example, agile methodologies and project management guidelines—situating how such frameworks are used within the corporate environment to ensure the success of innovative initiatives in education.

This applied approach seeks to demonstrate not only what should be done, but also why and how to do it in the most effective manner within the given context, thereby providing a solid basis for the decisions made throughout the project.

2.1 Applied Rationale

2.1.1 **Business Area Rationale:**

In this section, the project rationale is discussed from both educational and market perspectives, that is, the reasons why the proposed VR/AR solution is appropriate in light of the demands and trends of the education sector in which MIRAI operates. Initially, relevant concepts from the educational sector that inform the initiative are addressed—including pedagogical principles and curricular guidelines—and subsequently, market best practices regarding the use of VR/AR in education are presented, highlighting how companies and educational institutions have been applying these technologies to improve learning processes.

The partner company, MIRAI, is embedded within the broader context of Brazilian basic education, which means that its solutions must align with national educational policies and contemporary pedagogical theories. A central concept in this context is that of active learning methodologies, which encourage students' direct participation in the construction of knowledge, as opposed to traditional practices centered on teacher exposition. This approach is supported by classical authors in education. As argued by Freire (1970), authentic learning occurs when a dialogical and horizontal relationship is established between educators and learners, valuing students' everyday experiences and prior knowledge. This perspective, which predates the digital era, anticipates the importance of interactivity: both pedagogical interactivity (meaningful exchange between teachers and students) and technological interactivity (students actively engaging with digital tools) are fundamental to the production of new knowledge.

In the case of VR/AR, there is a clear opportunity to concretize this Freirean principle—the student ceases to be a "mere spectator" and becomes an active agent in the process, exploring virtual environments, manipulating 3D objects, and making decisions within a simulated world. This active stance enables new knowledge to be constructed in connection with the learner's reality (whether physical reality or a virtual reality that simulates real-world situations), rather than in an alienated manner. In summary, from a pedagogical standpoint, the use of VR/AR aligns with the need to break with the "banking" conception of education, promoting educational practices in which "those who teach learn in teaching and those who learn teach in learning," to paraphrase Freire (1996). Immersive technology, when properly applied, can serve as a mediator of this process, offering means for more meaningful, contextualized, and collaborative learning.

Another relevant concept concerns the profile of new generations of students, often referred to as the Digital Generation or digital natives (Prensky, 2001). These students have grown up immersed in interactive technologies—video games, the internet, mobile devices—and therefore exhibit distinct expectations regarding learning. Prensky and other contemporary authors (such as Katie Davis) observe that today's students have cognitive styles shaped by the digital world: they are more responsive to multimedia stimuli, prefer experimental and rapid learning, and tend to lose interest in unilateral or overly abstract approaches.

Prensky (2010) argues that twenty-first-century schools must undergo radical change to meet the needs of this new audience of learners, who "spend hours focused on videos, social networks, or video games" yet often show disengagement in traditional lecture-based classes. He proposes a "Partnership Pedagogy," in which teachers and students act as active co-participants in learning, and suggests that the organic integration of digital technologies into school activities is a fundamental component of this transformation. In particular, Prensky emphasizes that students do not want education to be merely curriculum-relevant—they want it to be real, that is, connected to concrete problems and authentic life experiences.

VR/AR directly addresses this demand, as it literally brings elements of the real world (or simulates real-world scenarios) into the learning process, making content vivid and contextualized. This ability to render learning "real" can reduce many young people's perception that school is disconnected from their lives—a sentiment that, according to Prensky and also Gee (2004), is common after the early years of elementary education. Therefore, motivating digital learners requires methodologies that integrate playfulness, visual elements, and interactivity, while simultaneously challenging students with real-world problems. Virtual and augmented reality technologies, when employed in a planned manner, can meet these criteria: for example, an educational VR game can engage a student in a scientific mission (playful) within a laboratory scenario (visual and interactive) to solve a problem inspired by real situations (relevant and applied). Thus, from a conceptual standpoint, MIRAI's proposal to invest in VR/AR is grounded in theories that emphasize student-centered, interactive, and reality-connected learning—principles endorsed both by critical pedagogical literature (Freire) and by educational technology literature (Prensky, Davis, etc.).

Additionally, it is important to situate the initiative in relation to curricular guidelines and competencies required in contemporary secondary education. As noted, the BNCC incorporates Digital Culture as a cross-cutting competence, encouraging the critical and creative use of technologies by students. Beyond this, the BNCC advocates, across various subject areas, the use of investigative methodologies, problem solving, and integrative projects. An example can be found in the specific competencies of Natural Sciences and Mathematics, which value students' ability to model real-world problems, analyze data, and understand phenomena through inquiry. AR/VR can be instrumental in this regard—for instance, by simulating a Physics experiment in VR whose results students must analyze, or by using AR to project graphs and information onto the physical world to assist in solving a mathematical problem. Such applications reinforce inquiry skills and critical thinking, aligning closely with the BNCC's expectation of forming students who are protagonists, "authors of their own lives and their own time" (in the terms of the document). Moreover, AR/VR can contribute to Interdisciplinarity, another key concept in modern secondary education: a well-designed immersive experience can simultaneously involve content from history, geography, and the arts (e.g., a virtual visit to an archaeological and cultural site), or integrate chemistry and biology (a virtual laboratory addressing biochemistry). This capacity to articulate multiple disciplines within a single activity reflects the integrated learning pathways proposed by Brazil's New Secondary Education model, suggesting that technology can practically facilitate the transition to more flexible, project-centered educational models.

Finally, it is relevant to understand MIRAI's educational business vision. As a company focused on customized solutions for education, MIRAI operates in partnership with schools and education networks, often developing tailored platforms, digital content, and learning management systems. Concepts such as Education 4.0—which brings the logic of the Fourth Industrial Revolution into education, emphasizing technology, personalization, and the development of future-oriented skills—influence the company's strategies. MIRAI seeks to position itself as a provider of educational innovation, which implies aligning its solutions with market best practices while also addressing the specific needs of its clients (which may range from elite private schools to public education networks in challenging contexts). Consequently, notions such as digital inclusion, personalized instruction, and adaptive learning are part of the company's lexicon and guide the applied justification of the project. A VR/AR solution, for example, must be inclusive (considering access for students with disabilities, such as implementing accessibility features within the virtual experience) and must allow for personalization (e.g., different difficulty levels or exploration paths for students with diverse learning paces). These requirements derive from contemporary educational concepts—such as inclusive education and pedagogical differentiation—which MIRAI adopts in its instructional design policies. Therefore, the project's foundation would be incomplete without considering these concepts from the partner company's educational sector: innovation with pedagogical purpose, adherence to educational policies (BNCC), and commitment to inclusion and personalization. All these elements converge to justify, from a business standpoint, why investing in VR/AR is appropriate: to offer more effective, engaging, and accessible learning experiences that meet student expectations and the demands of an updated and equitable education.

The adoption of virtual and augmented reality in education has moved beyond an experimental phase to become a concrete and growing trend in the global EdTech market. Numerous projects, products, and studies have demonstrated in practice the benefits of these technologies in educational settings, establishing a set of best practices that serve as references for the development proposed by MIRAI. In this subsection, some of these market practices are highlighted, illustrating how VR/AR is being used and for what purposes, as well as the observed advantages and limitations.

From the perspective of successful implementations, examples can be cited across different educational levels. One of the most widespread applications of VR is the use of virtual field trips: schools have employed VR headsets to take students to museums, historical sites, space explorations, or geographically inaccessible locations. These immersive experiences break temporal and spatial barriers, offering rich experiences without the costs and logistics of real-world excursions. For instance, students can “walk” through the streets of Ancient Rome, exploring in 360° what life was like in that civilization, or fly over mountainous systems in geography classes. Forbes (2021) listed “historical tours and space travel” as one of the main ways to use VR in basic and higher education, precisely due to their strong pedagogical and engagement appeal. Similarly, in natural sciences, VR has been used to simulate complex experiments and phenomena: companies such as Labster have developed virtual chemistry and biology laboratories in which students can safely conduct chemical experiments (virtually mixing reagents and observing reaction outcomes) or dissect an organism in virtual reality, all with a high degree of interaction. Such simulations not only reduce costs and risks (e.g., by not using real reagents), but also allow for unlimited repetition—students can attempt experiments as many times as needed, exploring scenarios without fear of failure, something traditional practical classes do not always permit.

This democratizes access to cutting-edge educational experiences, particularly benefiting institutions with limited infrastructure, and has a significant inclusive impact: as noted in a recent report, VR/AR can be a game changer in contexts such as Brazil, compensating for the lack of physical laboratories in many schools and democratizing access to high-quality experiences, despite the initial hardware cost still being a diminishing barrier.

Another emerging practice is the use of augmented reality in the classroom through mobile devices or tablets. AR stands out for overlaying digital information onto the real world, which has been leveraged to materialize abstract concepts within students’ physical environments. For example, biology teachers can use AR applications so that, when pointing a tablet camera at an image in a textbook, a pulsating 3D model of a human heart appears, which students can observe from different angles. There are AR applications that project miniature solar systems in the middle of the classroom or cause geometric figures to “emerge” from printed paper to support mathematics learning. A notable practice is the use of physical objects combined with AR, such as the Merge Cube—a plastic cube with patterns that, when viewed through a tablet or smartphone camera, transforms into different virtual objects (an interactive globe, a rotatable human brain, etc.). This approach provides students with tactile feedback (holding the cube) while they see a hologram over their hands, making the experience multimodal. Best practices in educational AR emphasize the need for a clear pedagogical purpose—the technology should not be a mere embellishment, but rather add instructional value. For instance, using AR to display molecules in 3D in organic chemistry learning is considered beneficial, as molecules are three-dimensional structures that are difficult to visualize mentally; AR helps reveal what is normally invisible to the naked eye, facilitating spatial and functional understanding of chemistry. Conversely, using AR merely to “animate” a textbook character without connection to a specific learning task would be a frivolous application. Therefore, successful market practice always integrates the technological and didactic dimensions: each virtual element introduced must fulfill a learning objective (whether to motivate, explain, or enable practice). Renowned companies, such as Google (with the now-discontinued Google Expeditions and later AR in Search), as well as educational startups, have published exemplary use cases of this nature.

The reported advantages of using VR/AR in education are numerous. In summary, the following stand out:

a) Increased engagement and motivation—students tend to be more attentive and participatory in immersive activities, often describing them as enjoyable and memorable.
b) Meaningful learning and greater retention—by experiencing a situation (even virtually), students associate content with practical experience, which favors information retention and deep understanding, avoiding rote memorization;
c) Visualization and comprehension of complex concepts—abstract, very small, or very large phenomena can be virtually modeled (e.g., visualizing forces acting on a 3D mathematical function in VR, or a magnetic field in AR), making tangible what is difficult to imagine through verbal explanation alone;
d) Safe environments for error and training—VR simulations provide controlled environments where mistakes have no real consequences, allowing students

to practice laboratory procedures, physics scenarios, or even skill training without fear;

e) Inclusion and accessibility—VR can benefit students with certain disabilities, for example by allowing a wheelchair user to virtually “traverse” rugged terrain in geography that might be inaccessible in reality; moreover, accessibility features (audio description, captions, etc.) can be incorporated into virtual environments to support students with visual or hearing impairments.

These advantages support the notion that immersive technology is not merely a “gadget,” but rather a transformative tool that, when well utilized, enhances both the quality and equity of education.

Naturally, there are also challenges and limitations associated with the use of VR/AR in education, as identified in market experiences. One of the most frequently cited challenges concerns cost and infrastructure: although the prices of VR devices are decreasing, acquiring a set of VR headsets for an entire class remains costly for many institutions, particularly in the public sector. In addition, compatible computers or smartphones, good connectivity, and adequate physical space are required (in the case of VR, a safe environment for movement is necessary). Thus, logistical concerns are significant. However, trends such as the use of standalone headsets (e.g., Oculus Quest, which does not require a PC) and device-sharing models (student rotation) have partially mitigated this issue. Another limitation involves the learning curve and teacher training: implementing VR/AR requires that teachers be comfortable with the technology and integrate it into lesson planning. Teacher training programs for VR/AR use are therefore critical; without them, there is a risk that the tool will be underutilized or misaligned with pedagogical objectives. Additionally, in the case of VR, some studies report issues of fatigue or discomfort: prolonged sessions may cause motion sickness (cybersickness) in some users or visual strain, indicating that educational use should be moderated (e.g., experiences of 15–20 minutes rather than extended durations). In the case of mobile-based AR, distraction is a concern—if not well managed, tablet use in class can divert attention (students may switch to other applications, etc.). Consequently, best practices always recommend activity designs that keep students focused on the task (goal-oriented gamification, teacher monitoring, etc.). Finally, a technical limitation to mention is that developing VR/AR content can be complex: producing rich 3D environments and virtual models requires specialized knowledge (3D design, programming, VR UX). This constitutes one of the bottlenecks to adoption—many schools would like to use VR/AR but lack curriculum-aligned content. To address this, the market has seen the emergence of immersive content libraries and platforms: marketplaces where teachers can download experiences created by other educators. MIRAI's present project takes this into account by proposing a solution in which teachers can build or customize VR experiences without needing to program, using pre-existing resources (such as 3D objects from a repository). This "open platform" approach is inspired by successful market initiatives such as Immersive VR Education and the Merge EDU platform, which provide collections of reusable educational virtual experiences and objects.

In summary, market practices indicate that VR/AR in education represents a rich frontier of possibilities, already yielding concrete results in various contexts. Best practices emphasize clear pedagogical planning (VR/AR must serve the lesson's objective), curricular integration (alignment with competencies such as those defined by the BNCC), teacher preparation, and outcome evaluation (collecting student feedback and measuring learning impacts). For MIRAI, observing these practices is essential to validate the proposed approach. Growing global investment in the area (with projections of approximately USD 14 billion in the immersive EdTech market by the middle of the next decade) and successful cases suggest that investment in immersive education is well founded. Educational businesses that incorporate these technologies with pedagogical purpose have the potential to lead a transformation in teaching and learning, delivering greater value to their clients (schools, students, and families) while simultaneously contributing to education's response to contemporary challenges—namely, the formation of citizens who are competent in the digital world and capable of applying knowledge critically and creatively.

2.1.2 **Technological rationale for the solution:**

This section addresses the technological foundation of the project, detailing the technologies considered and the technical justification for the choices made, with particular emphasis on the selection of the Godot engine as the development platform for VR/AR experiences at MIRAI. It is divided into two parts: first, a review of the development technologies and methodologies applied or evaluated in the project—including software architectures (such as serverless), Artificial Intelligence techniques (e.g., NLP – Natural Language Processing), and data analysis tools (Business Intelligence) relevant to the context. Subsequently, the technical justification for the choice of Godot is presented, situated within the company's technological context and compared with alternatives, highlighting its advantages in the proposed scenario, as well as any limitations and how they were mitigated.

The project in question is situated at the intersection of software development, 3D computer graphics, and online educational applications. Accordingly, it was necessary to review a broad set of modern technologies that could compose the solution, ensuring scalability, flexibility, and performance in line with MIRAI's needs. One of the central architectural decisions was the adoption of a serverless backend architecture in the web solution that complements the immersive application. Rather than relying on continuously maintained dedicated servers, a serverless approach using cloud services (such as AWS or similar providers) was chosen to host backend functionalities (APIs, databases, and object storage). The rationale for this choice aligns with industry trends: serverless architecture offers automatic on-demand scalability—computing resources scale up or down automatically according to the number of users, without manual intervention—and eliminates the need to manage server infrastructure, allowing developers to focus on business logic. Additional advantages of this model include cost-effectiveness (payment is made only for actual usage, with no expenditure on idle capacity) and ease of continuous deployment (individual functions can be updated independently, with minimal environment configuration). For MIRAI, whose objective is to offer customized solutions to different clients, serverless architecture provides the agility required to serve multiple schools of varying sizes—the solution can support anything from a school with 50 users to a network with 5,000, scaling according to demand without significant reengineering. The absence of a need to maintain servers 24/7 also reduces the DevOps burden on the company's team, aligning with a resource optimization strategy (focusing on feature development while outsourcing infrastructure management to the cloud). Naturally, potential disadvantages of this choice were considered, such as the complexity of orchestrating multiple services and dependence on a cloud provider (vendor lock-in risk). However, these aspects were mitigated by designing the solution in a modular manner and using open standards where possible (for example, compatible containers and standardized RESTful APIs), which in theory allows workloads to be migrated between providers if necessary.

Another class of technology reviewed for possible inclusion was Artificial Intelligence, particularly Natural Language Processing (NLP). In the context of an immersive educational platform, NLP could be employed in features such as chatbots or interactive virtual tutors within the experience (for example, a VR-based virtual assistant that answers students' questions in natural language), or automated analysis of students' open-ended responses. Although NLP is not the primary focus of the project, its relevance as a supplementary pedagogical support functionality was discussed. For instance, using NLP techniques, it would be feasible in the future to implement a formative assessment tool: at the end of an immersive experience, a student could describe what they learned, and an NLP algorithm would analyze the response, providing the teacher with a summary or indicating which concepts were mentioned versus expected. Large language models (such as GPT, from OpenAI) open interesting possibilities in this regard, but they also present challenges, such as the need for connectivity to external services and concerns regarding student data privacy. Within the scope of this undergraduate thesis, it was decided not to integrate NLP in depth into the initial prototype; however, the technological review maps this path for future evolution. MIRAI itself expressed interest in eventually incorporating AI assistants into its educational products, whether for personalized student support or engagement analysis. Therefore, maintaining an architecture compatible with the addition of AI modules (for example, via specialized APIs) is part of the technological rationale.

With regard to Business Intelligence (BI) and educational data analysis, this constitutes a highly relevant component for educational technology companies. A VR/AR solution applied to education can and should collect usage data that serve to evaluate effectiveness and continuously improve the tool. During the foundation phase, BI methodologies focused on education (Learning Analytics) were surveyed. The idea is for the system to record, for example, which virtual objects the student explored, how much time was spent in each part of the experience, whether proposed tasks were completed, and so forth. With these data, the school (or MIRAI) can extract indicators such as which content generates greater engagement, where students encounter the most difficulty, or the class's average performance in a given simulation. BI tools allow these indicators to be consolidated into dashboards for educational managers, supporting evidence-based school management. Studies in data-driven education show that the ability to make decisions grounded in data creates a virtuous cycle of improvement, benefiting students and educators alike. Thus, including BI components in the solution adds tangible business value, differentiating it (for example, by enabling the school to view student learning reports within VR). The technical foundation encompassed the choice of an appropriate database (a cloud-based relational database was selected for structured platform data, along with S3-like object storage for virtual world assets) and the feasibility of implementing event tracking within the Godot application (which was achieved via API calls logging relevant interactions). As a result, the platform can, for instance, count how many students completed a VR experience and send these data to an analytics module. In terms of specific BI tools, integration with open-source solutions (such as Metabase or Grafana) or native cloud visualization services was considered. Again, although such integrations are limited in the prototype (perhaps only basic logs), the applied rationale foresees this analytical dimension as part of the technological justification: it is not sufficient to implement VR/AR; it is also essential to measure its impact and operation.

In addition to these, other auxiliary technologies were reviewed: microservices architecture (useful should the project grow and require component separation, although initially a simple monolithic backend structure was chosen to ensure rapid delivery), web APIs (the backend exposes a RESTful API to allow the Godot application to retrieve content and register data, following REST principles to facilitate maintenance and potential future integrations with other platforms), and interoperability standards (such as the glTF format for 3D models, which was adopted to ensure that objects created in various 3D tools could be easily imported into Godot and the web platform). It is also worth noting the use of the OpenXR standard for extended reality, which was identified as fundamental for ensuring compatibility across different VR devices. OpenXR is an open API maintained by the Khronos Group that standardizes access to VR/AR features across multiple platforms (Windows MR, Oculus/Meta, HTC Vive, etc.). Adopting OpenXR in the solution means that the Godot application can run on multiple devices without significant modifications. This decision was based on best-practice analyses: when evaluating immersive educational applications, the use of OpenXR as a foundation is recommended, complemented by specific tools (such as XR Tools plugins or the Meta Toolkit in Godot) for additional functionality, with the understanding that these plugins provide ready-made examples (virtual menus, hand controls, etc.) but require attention to version compatibility and update documentation. In summary, the technological review served to assemble an architectural ecosystem suited to the project: a web frontend (an interface for teachers to build experiences, developed using a modern framework—React/Next.js was chosen due to team familiarity), a serverless cloud backend (APIs in .NET 6 in containers, RDS database, and S3 storage, ensuring scalability and low coupling), and the Godot client (a multiplatform VR/AR application that downloads experience definitions from the backend and executes them on the student's device). This set aligns with several contemporary methodologies (cloud-native design, continuous delivery, format standardization) and was selected to meet the performance, cost, and maintenance requirements identified in collaboration with MIRAI.

A central point of the project's technological rationale is the choice of the Godot engine for the development of VR/AR applications, instead of other market engines such as Unity or Unreal Engine. Godot Engine is an open-source platform for developing 2D/3D games and applications that, in recent years, has gained maturity and increasing adoption. The decision to use it in the project was based on technical criteria aligned with MIRAI's needs and the educational objectives, as detailed below.

First, Godot's open license and absence of costs were significant factors. Unlike proprietary engines (Unity offers free plans with limitations and paid licenses for certain uses; Unreal requires royalties for commercial projects above a certain revenue threshold), Godot is entirely free, requiring no royalties or subscriptions regardless of project size or commercial purpose. For MIRAI, this translates into reduced long-term costs and avoidance of dependency on a specific vendor. From a business standpoint, a solution built with Godot can be freely distributed to partner schools without legal concerns, and the company can commercialize it without passing licensing costs on to clients—a competitive advantage, for example, in proposals to public-sector organizations. Beyond the financial aspect, Godot's open-source nature provides transparency and control: the engine's source code is available, allowing MIRAI's technical team to inspect or even extend specific functionalities if necessary (albeit requiring high specialization). This possibility of deep customization is valuable in bespoke solutions, as highly specific educational application requirements can be addressed by the community or the internal team—something infeasible with closed platforms.

Another strength of Godot is its lightness and efficiency. It is known for having a lean runtime and for performing well even on modest hardware. In comparative tests, simple Godot applications often have smaller distribution sizes and lower resource requirements than equivalent Unity applications, for example. This is particularly important in the educational context, where available devices are not always state-of-the-art. Many school laboratories have mid-range computers, and in the case of VR, even dedicated headsets (such as Meta Quest) have limited hardware compared to gaming PCs. Godot, being optimized and having low overhead, proved capable of achieving satisfactory performance in these environments, which is crucial to ensure a smooth experience (90 FPS) and to avoid latency or stuttering issues that could hinder classroom use. The engine provides configurable rendering options (in Godot 4, Mobile, Compatibility, and Forward+ renderers are available), and the Mobile renderer is recommended for VR on PC or mobile devices, as it simplifies effects to prioritize performance. Additionally, to support VR, Godot integrates OpenXR natively (from version 3.2 onward, and especially in Godot 4), as previously mentioned. This means developers do not need to deal with proprietary SDKs from each manufacturer; enabling the OpenXR module allows the engine to communicate with VR headsets from different brands. This native and continuous OpenXR support in Godot was one of the central elements of the technical choice, as it ensures broad device compatibility without additional development effort. For example, the same Godot application can run on an Oculus Quest 2, an HTC Vive, or a Windows Mixed Reality device, and even on AR devices such as HoloLens (provided the interface is adapted), respecting each platform's specifics. This directly addresses MIRAI's need for a portable and versatile solution—different schools may have different equipment, and the platform cannot be restricted to a single hardware vendor.

Compatibility with and support for open standards constituted another justification. Godot works well with industry-standard formats, facilitating workflow integration. As documented, Godot handles 3D models in glTF (open glTF 2.0 format) and other formats (OBJ, FBX via importers), PNG/JPEG images, MP4 videos, MP3 audio, and so forth, ensuring interoperability between content created on the web platform (which may use models from online libraries) and execution within the engine. This was validated during the project—the virtual scene assembled by a teacher (described in JSON by the web system) references glTF models and textures; the Godot application then downloads these files from storage and loads them into the scene at runtime. Objects come to life in the immersive environment exactly as configured during the authoring phase. The seamless integration between the web editor and the Godot runtime is only possible due to support for these standards and the stability of Godot's APIs for dynamic resource loading. Moreover, Godot is multiplatform: the same project can be exported to multiple platforms (Windows, Linux, Android, Web, etc.). In the specific case of mobile and standalone VR devices, the Godot project exports to Android (since devices such as Quest run an internal Android OS). The entire export and deployment process on mobile VR devices is relatively straightforward with Godot, requiring configuration of the Android SDK and enabling OpenXR in the project settings, as per documentation (Godot 4.4 even includes specific presets for Meta Quest). This comparative simplicity accelerates development and distribution: the team was able to quickly test the prototype on available Meta Quest 2 headsets using the official Meta Quest Plugin for Godot (also open-source), which automates the signatures and configurations required by Meta.

Another element of the technical justification is the availability of specialized XR tools and plugins within the Godot ecosystem. Although the Godot XR community is smaller than Unity's, it has produced useful components. Notably, Godot XR Tools is an official plugin that provides a range of ready-made nodes and scenes for VR: nodes for hand representation (VR controllers), raycasts for distance interaction (commonly referred to as a "laser pointer" for virtual menus), locomotion (teleportation, etc.), and more. These resources accelerate development by avoiding the need to reinvent basic VR interaction functionality. When evaluating Godot for the project, XR Tools was tested and found to offer practical examples—such as a radial menu that follows the user's hand and a grab-and-drop system—that can be adapted to educational content. Similarly, for the specific case of Meta Quest, the Meta OpenXR Plugin (Meta Toolkit) provides fine-grained integration with hardware features (for example, passthrough to view the real environment through cameras, or hand tracking). The foundation documented that these plugins provide implementation shortcuts but require care: they must be kept up to date with the engine and OpenXR versions in use, implying attention to release notes and potential minor adjustments. This does not detract from Godot itself; rather, it demonstrates that the community and third parties (including Meta) are investing in making Godot a robust XR platform. MIRAI considered this a form of validation: support from major companies indicates confidence and continuity.

Comparatively, potential drawbacks of choosing Godot were also identified, underscoring that the decision was made consciously. One issue is relative maturity: until recently, Unity and Unreal dominated the VR/AR field, offering extensive documentation, large communities, and numerous active plugins. Godot, being newer in VR support (particularly with Godot 4, released in 2023 with major improvements), still has a smaller XR community, fewer specific tutorials, and some evolving features. This meant the development team faced a steeper learning and investigation curve—for example, it was necessary to explore demo repositories and forums to resolve VR input details in Godot 4, as references were scarcer than in Unity. However, this gap is closing rapidly: Godot's official XR documentation is well structured, and the GitHub and Discord communities proved highly supportive. Moreover, MIRAI assessed that by adopting Godot, it is investing in internal expertise in an emerging technology, which in the medium term may become a differentiator (as more companies migrate to open-source solutions to avoid Unity costs, for instance, MIRAI will already have consolidated expertise). In terms of functionality, Godot meets virtually all project requirements; only very advanced features (such as cutting-edge photorealistic graphics or ultra-realistic physics) are areas where Unreal Engine might have an advantage—but these are not priorities in the educational context, where simplicity and visual clarity are more important than hyper-realism. Therefore, it was concluded that the advantages outweigh the limitations in this specific case. As summarized in the project documentation, "the choice of Godot stems from its open-source nature, lightweight performance, and support for VR via OpenXR, enabling broad device compatibility without licensing costs." This statement succinctly captures the technical rationale underlying the decision.

In conclusion, the Godot engine proved to be technically appropriate and strategically aligned with MIRAI's project. It provides the necessary pillars to build multiplatform

VR/AR experiences efficiently, economically, and in integration with the rest of the chosen architecture. The decision to adopt Godot also carries an element of innovation—few educational solutions in the Brazilian market have been developed on this engine to date, which may further distinguish the company if successful (as a use case of Godot in EdTech). From an academic and applied validation perspective, it was essential to justify this choice not by subjective preference, but by objective criteria: zero licensing costs, open and customizable code, broad compatibility (OpenXR), strong performance on modest hardware, available XR tools, and ease of integration with the proposed web architecture. The development results thus far confirm this justification—for example, when integrating the Godot application with the backend via HTTP calls, the workflow functioned as expected, dynamically reconstructing VR scenes from received descriptions (JSON) and assets downloaded from the cloud. The engine handled object instantiation, property configuration, and user interaction responses effectively, demonstrating its capabilities in practice. Accordingly, Godot is validated as a solid technical choice for the project, capable of delivering the envisioned educational immersive experience while fitting within MIRAI’s business strategies of using customizable, license-free, and long-term sustainable solutions.

2.1.3 **Fundamentals of Management and Development Methods:**

In addition to educational and technological foundations, it is crucial to consider the project management and software development methods that underpin the conduct of work within MIRAI’s corporate environment. The implementation of an innovative solution involving VR/AR requires not only sound ideas and competent programming, but also a structured project approach to ensure that objectives are achieved within schedule, budget, and the expected quality standards. In this section, we review the agile development methodologies and DevOps practices adopted, as well as project management guidelines based on best practices (such as PMBOK), contextualizing how these methodologies are applied in the day-to-day corporate environment of the partner company.

MIRAI, as a technology company, follows the industry trend of adopting agile methodologies in the management of its software projects. Agile methodologies (Scrum, Kanban, XP, among others) are characterized by dividing work into short delivery cycles (iterations or sprints) and emphasizing flexibility and continuous collaboration. This contrasts with traditional waterfall development models, in which all stages are planned in detail from start to finish and subsequent changes are costly. In the context of this project, an approach inspired by Scrum was adopted: incremental deliveries were planned every few weeks, allowing partial progress to be assessed and functionalities to be adjusted according to feedback from both academic supervision and MIRAI representatives. This choice is justified because innovative projects—such as integrating VR into education—entail a high degree of discovery along the way; agility provides the capacity for rapid adaptation. As noted by Fernanda Gaona (2025), “agile methodologies make processes and tasks more dynamic, flexible, and collaborative” in project management, enabling timely course corrections during development. In the case of our project, this meant that, for example, if a given VR functionality proved unfeasible or overly complex within a sprint (such as implementing manual gesture recognition), we could revise the scope and replace it with an alternative (such as using interface controllers instead of gestures) in the subsequent iteration, without jeopardizing the entire project. Furthermore, the agile focus on delivering value in each cycle ensured that there was always something functional to present—first a simple prototype of a navigable VR scene, then backend integration, followed by a minimal interface for the teacher, and so forth. This cadence of incremental deliveries kept all stakeholders (advisors and the MIRAI team) engaged and enabled continuous feedback to be gathered.

Alongside agile methodologies, a DevOps culture was adopted to integrate development and operations stages. The term DevOps refers to a set of practices aimed at shortening the software development lifecycle while delivering features, fixes, and updates with quality and reliability. It seeks to break down traditional barriers between development (Dev) and operations (Ops) teams by promoting collaboration, automation, and continuous integration. In the MIRAI project, despite the small team size, we incorporated DevOps principles such as: the use of a Git repository integrated with continuous integration (CI) pipelines to automate builds and tests on each significant commit; infrastructure-as-code deployment scripts (in this case, using AWS CloudFormation or Terraform to describe serverless resources); and basic environment monitoring (centralized logs and service uptime checks). The objective was to ensure that, as new functionalities were developed, they could be quickly integrated and made available in testing or production environments, minimizing human configuration errors. In practical terms, for example, a GitHub Actions pipeline was set up so that, with each push to the backend's main branch, automated tests were executed and, if successful, the new API version was deployed to the cloud. This illustrates the DevOps mantra of continuous delivery: smaller, more frequent changes rather than large, infrequent releases, thereby reducing risk. TOTVS (2021) defines DevOps as "a modern approach to software development that seeks to facilitate deliveries, adding greater agility and quality." This was precisely the intended benefit—accelerating deliveries without compromising quality. Test and deployment automation helped maintain quality control, and close collaboration (developers working alongside those responsible for cloud maintenance) avoided surprises when making the system available. Within MIRAI's environment, there was already a predisposition toward DevOps, as the company operates cloud services and values rapid deployments to serve its clients. Thus, the project aligned with this culture, leveraging tools already in use (Docker, CI/CD pipelines, etc.). In summary, Agile + DevOps provided the methodological framework to develop the solution iteratively, adaptively, and with reliable deployment. This was fundamental, as it allowed the experimental nature of VR aspects to be addressed without losing sight of deadlines and overall system integrity.

In parallel with agile and DevOps methodologies at the level of technical execution, MIRAI incorporates in its project management practices references to best practices consolidated in the PMBOK (Project Management Body of Knowledge) guide by the PMI. Unlike Agile, which focuses on adaptive execution, PMBOK offers a comprehensive set of guidelines for managing projects, covering areas such as integration, scope, schedule, costs, quality, resources, communications, risks, and procurement. In the corporate environment, especially when dealing with contracts and client deliveries, many of these aspects must be formally considered. PMBOK is not a closed methodology per se, but rather a guide of standardized knowledge and processes that can be combined with agile methods—and it was this hybrid approach that permeated the project. For example, from a scope perspective, even while working with agile iterations, a clear Scope Statement was defined at the outset (identifying the solution's essential functionalities and the success criteria for both the TCC and MIRAI). This was important to avoid scope creep and maintain focus on what would deliver results. PMBOK techniques such as the WBS (Work Breakdown Structure) were used to decompose the main deliverables, and each agile sprint was planned to advance components of this WBS. Thus, the benefits of both worlds were combined: Agile's flexibility with PMBOK's comprehensive view. One of PMBOK's principles is the standardization of language and processes in project management, which facilitates communication among teams and stakeholders. In the project, this standardization was adopted when reporting progress to MIRAI's management—for instance, when discussing project risks, PMBOK terminology was used (risk identification, qualitative analysis, response plans) to communicate to leadership the potential threats (such as "risk of delay in VR hardware delivery" or "risk of technical difficulty X"). This lent greater credibility and clarity to reports, demonstrating professionalism in execution.

The PMBOK guide also emphasizes the iron triangle (time, cost, quality) and the need for balance. Based on these best practices, a formal schedule and milestone tracking process was implemented at MIRAI. Although Agile addresses sprints, at a macro level it was necessary to manage a final delivery date (submission of the TCC/product) and key milestones (e.g., completion of the written chapter, alpha software demonstration, intermediate evaluation with users). Using management tools (a combination of Jira for agile management and Microsoft Project for a high-level view, for example), it was possible to monitor whether the project was on track. Indeed, the application of PMBOK concepts such as integrated change management proved useful: when a scope change was required—such as deciding to reduce the number of VR scenarios from three to two to ensure quality—this was formalized in a meeting with supervision, analyzing schedule impacts and communicating them to all involved. This posture aligns with PMBOK's guideline of "integrating knowledge areas," whereby changes should not be adopted without considering side effects. The purpose of PMBOK is to clarify understanding of various project aspects (schedule, quality, costs, etc.) within a single project, and this clarity was reflected in our case through the maintenance of organized and accessible documentation (project plan, test plan, etc., albeit adapted to the scale of a TCC).

In companies like MIRAI, which handle multiple projects simultaneously, the use of a standard project management framework inspires client confidence. MIRAI frequently references PMBOK in its commercial proposals, indicating that its project managers follow international standards. Thus, bringing the VR/AR project into alignment with this framework was also a way to ensure quality and professionalism. For example, quality assurance processes were applied—regular code reviews, pilot software testing with team members not involved in day-to-day development (to obtain a fresh perspective and identify usability issues), and validation of pedagogical content by a guest specialist (a trusted teacher associated with MIRAI). All of this aligns with PMBOK knowledge areas related to quality and resources (engaging the right people and verifying that the product meets requirements). Moreover, risk management was a highlighted point, given the exploratory nature of the project: early identification included technical risks (e.g., the possibility that performance on mobile devices would be unsatisfactory) and external risks (dependency on equipment delivery, as mentioned). For each risk, mitigation strategies were developed (in the performance example, preparing a backup PC VR version of the app in case mobile failed; for equipment, having a contingency plan to borrow from another institution). This preparation was inspired by PMBOK-recommended practices for dealing with uncertainty and proved valuable when some risks materialized—for instance, there was a delay in authorization to use a school computer lab for testing, but an alternative plan was already in place to test with a smaller group at another location, ensuring that the testing schedule was not lost.

Finally, it is relevant to mention the integration of corporate governance into the project. As a partner, MIRAI maintained an interest in the results; therefore, a structured communication routine was adopted (biweekly status meetings with a company-designated manager, summary emails at the end of each sprint, and product demonstrations during reviews). This aligns with what PMBOK describes in the communications area: sharing the right information with the right parties at the right time. In other words, transparency and proper documentation avoided misunderstandings and continuously aligned expectations. This is a fundamental management lesson: many projects fail not due to technical problems, but because of communication and alignment failures. By applying best practices, we were able to maintain MIRAI's leadership support and positive engagement from all parties, even when adjustments were necessary.

In summary, the project management foundations employed—combining the agility and integration of Agile/DevOps with the structure and comprehensiveness of PMBOK—provided the project with a robust execution framework. In the partner company's corporate environment, this translated into organization, predictability, and delivery capability. For an academic project conducted in collaboration with a company, this balance was crucial: we had the freedom to experiment and pivot (thanks to Agile), without losing the commitment to concrete and well-managed deliverables (thanks to PMBOK). In this way, the applied foundation addresses not only what to develop, but also how to develop efficiently, ensuring that the VR/AR solution reaches a successful outcome while fulfilling both research and business partner objectives. This reflects a modern trend toward hybrid management, in which the best elements of multiple approaches are used to meet the specificities of each project. In accordance with best practices, the success of an innovative educational technology project lies both in the intrinsic quality of the solution (technology and pedagogy, as discussed in previous sections) and in the excellence of its execution—and the latter was actively pursued through the management methods and foundations outlined herein.

2.2 Specification and Development

This section details the technical specifications and development process of the solution, ensuring alignment with the partner company's standards and needs. It covers the system requirements, architecture choices, development methodology, and the testing carried out to validate the solution.

2.2.1 Requirements and Specifications

Functional Requirements: The system was designed with key functional requirements to meet user needs. These included:

a) Content Creation: Teachers must be able to create or upload interactive VR/AR educational content easily (e.g. virtual labs, 3D models for lessons).
b) Content Access: Students should access the VR/AR content through a user-friendly interface (via a headset or mobile app) and navigate lessons interactively.
c) User Management: The platform should support different user roles – for example, teachers (content creators), students (content consumers), and administrators (oversight of content and usage).
d) Classroom Integration: Teachers can organize content into classes or topics and distribute it to their students. The system should allow linking VR lessons to the school's curriculum or lesson plans.
e) Tracking and Feedback: Basic analytics or feedback collection (e.g. quiz scores or engagement metrics) to allow teachers and stakeholders to evaluate student performance and engagement with the VR content.

Non-Functional Requirements: The solution also needed to satisfy various non-functional criteria to align with corporate standards and ensure a good user experience:

a) Usability: The application must be intuitive for educators and students, requiring minimal training. A clean UI and simple controls (especially in VR mode) were prioritized.
b) Performance: VR content should run smoothly on target hardware (achieving stable frame rates and low latency to prevent discomfort). The system should handle multiple users/content sessions without significant lag.
c) Compatibility: The platform should be compatible with commonly available devices. For the MVP, support was focused on low-cost VR solutions (e.g. smartphone + Cardboard, and standalone VR headsets) to ensure accessibility.
d) Scalability: Though starting as a pilot, the architecture should allow scaling to more users, classes, or schools in the future without major redesign. This includes scalable backend services and content delivery mechanisms.

e) Security and Privacy: User data (especially student information) must be protected in compliance with data protection standards. Authentication is required for teacher and student logins, and content should be delivered securely. The solution should align with the company's IT security policies (e.g. password policies, data encryption for any stored personal data).
f) Maintainability: The system should be maintainable by the company's IT team post-handover. Clear code structure, documentation, and use of standard frameworks were required to ease future enhancements or bug fixes.

User Specifications and Use Cases: Several primary use cases guided the requirements:

a) Use Case 1 – Teacher creates a VR lesson: A teacher logs into the platform, uses a content editor or upload interface to create a VR lesson (for example, uploading a 3D model or configuring a virtual scenario), adds descriptive text and interactions (quizzes, labels, etc.), and publishes it to a class or group of students.
b) Use Case 2 – Student experiences a VR lesson: A student launches the VR application or viewer, logs in and selects the lesson assigned by their teacher. The student then engages with the immersive content (e.g. exploring a virtual environment or manipulating 3D objects), possibly answering questions or completing tasks within the VR lesson. Their progress or score is recorded.
c) Use Case 3 – Administrator reviews usage: An IT admin or project manager can review usage metrics such as number of lessons created, student participation rates, and system performance logs. This helps ensure the system is being used as intended and aids in identifying any technical issues or training needs.

These requirements and use cases were refined in collaboration with the partner company's stakeholders to ensure the solution would effectively address the identified educational challenges and fit the users' workflows.

2.2.2 Architecture and Technology

The solution adopts a client-server architecture with cloud integration, balancing processing between the user's device and backend services. On the client side, there is a VR-enabled application through which students and teachers interact with content. This client was developed using the Godot Engine (an open-source game engine) for the VR/AR functionality, chosen for its flexibility and cross-platform support. Godot's node-based architecture and support for OpenXR standards ensured that the immersive experiences could run on multiple devices (e.g., Windows PC, Android smartphones, or standalone VR headsets). On the server side, a web-based backend system handles content management, user accounts, and data storage. This backend exposes APIs that the client application uses to authenticate users, download VR lesson content, and upload any interaction data (such as quiz results).

The backend was implemented with standard web technologies in line with the company's IT ecosystem – for example, a Python/Node.js or Java-based web server (following the partner's preferred stack) with a database for storing user data and content metadata. The use of Godot for the client allowed the VR content to be packaged as a mobile or desktop application. All components were containerized and deployed on the company's cloud environment for the MVP, which aligns with the partner's infrastructure standards (e.g. using Docker images on their cloud or on-premises servers). The system also integrates with existing company services where appropriate; for instance, single sign-on was enabled so that teachers and students could log in with their existing school credentials, and content delivery was optimized to work over the school's network configuration.

Integrating the solution into the company's IT landscape involved ensuring compatibility with network policies and existing platforms. The application was designed to complement the school's Learning Management System (LMS) rather than replace it. For example, links to VR lessons or summary reports can be accessed through the LMS. Data exports (e.g., student performance data from VR quizzes) can be generated in formats compatible with the school's analytics systems. The deployment on the company's cloud was done in a sandbox environment initially, complying with the IT department's guidelines for new applications – including following their data security rules (firewalls, SSL encryption for data in transit, role-based access control matching the company's standards). This architectural approach ensured that the new platform could operate within the partner's existing technology ecosystem without disruption.

2.2.3 **Development and Implementation (MVP):**

The project followed an Agile development methodology, primarily Scrum, to iteratively build and refine the solution. The development was organized into short sprints (approximately 2-week cycles), each delivering incremental features. This approach allowed continuous feedback from stakeholders (including a few tech-savvy teachers who acted as beta testers) at the end of each sprint. Key ceremonies like sprint planning, reviews, and retrospectives were conducted to keep development aligned with objectives and schedule. This iterative process proved especially useful given the innovative nature of the project – for example, early user feedback led to UI/UX adjustments to make the VR interface more intuitive for students. The Agile approach also ensured flexibility to accommodate changes (such as tweaking a requirement or improving performance) without derailing the project timeline.

The focus was on developing a Minimum Viable Product (MVP) that encapsulated the core functionalities – content creation, content delivery in VR, and basic user management – within the limited project timeframe. Development started with foundational tasks: setting up the backend infrastructure and building a prototype VR scene to test technical feasibility. Once the groundwork was done, functional features were added incrementally. By mid-development, a working prototype allowed the team to perform an internal pilot: for instance, a sample VR lesson (a virtual chemistry experiment) was created and a few students were invited to try it in a controlled setting. This internal pilot helped in fine-tuning the system (resolving minor bugs and improving instructional design within the VR lesson).

After validating the MVP in-house, the solution was deployed for a pilot phase in the partner company's environment. The deployment process involved installing the server components on the company's test server and distributing the VR client application to a small group of end-users. For the educational pilot, this meant installing the VR app on a set of school-owned devices (e.g., a cart of Android smartphones with VR viewers) and on a couple of standalone VR headsets provided for the project. The pilot was conducted in a real class setting: a partner school's classroom was used where one teacher integrated the VR lesson into their teaching and a class of students experienced it as part of their curriculum. During this pilot, the development team worked closely with the company's IT staff to monitor system performance on their network and to ensure there were no compatibility issues. The deployment in the test environment was gradually scaled to a production-like environment once stability was confirmed. By the end of this phase, the MVP was fully running on the company's infrastructure, with the pilot users successfully using the system in day-to-day operations.

This section outlines the computational architecture developed and defines the quantifiable metrics used to evaluate the project's success.

The solution consists of an integrated Hardware and Software ecosystem designed to democratize the creation and consumption of Virtual Reality (VR) content in high schools. The architecture is divided into two primary modules that operate synchronously via the cloud, supported by Amazon Web Services (AWS) infrastructure:

1) The "Experience Builder" (Web Authoring Module): The core innovation of this project is a "No-Code" visual editor accessible via web browsers. Developed using Next.js and powered by the Three.js graphics library (via React Three Fiber), this interface abstracts the technical complexity of game engines. It allows teachers to act as creators through a WYSIWYG (What You See Is What You Get) environment, featuring:
    a) Scene Composition: Teachers can import 360º environments (Skyboxes) and position 3D models (glTF/GLB formats) from a curated library or external uploads.
    b) Interactive Design: A simplified tooling system (Transform Controls) allows users to manipulate object scale, rotation, and position. Teachers can attach multimedia elements (spatial audio, 2D images, video panels) and define logic triggers (e.g., "Hotspots" that display information or link to different scenes) without writing a single line of code.

c) Data Serialization: The created experience is saved as a proprietary JSON structure, which describes the scene hierarchy, object properties, and asset references stored in Amazon S3. This lightweight data format acts as the "DNA" of the lesson, ensuring fast transmission over school networks.

2) The VR Client Application (Runtime): On the student's side, the solution utilizes a native application developed in the Godot Engine 4.x, optimized for standalone headsets like the Meta Quest 2. Unlike traditional apps with hardcoded content, this client functions as a "Universal Interpreter." It authenticates the student, fetches the JSON file generated by the teacher from the backend, and reconstructs the 3D scene in real-time. This approach ensures that updates made by the teacher on the web are immediately available to students without the need to update the application itself.

The project aims to deliver quantifiable results across operational efficiency and pedagogical effectiveness, measured through a "Before vs. After" comparison.

1) Reduction in Content Production Time: The primary technical contribution is the optimization of the development pipeline. The project aims to reduce the time required to create a custom VR lesson by approximately 90%.
   a) Baseline: Traditional development (Unity/Unreal) requires 40+ hours of engineering time per simulation.
   b) Target: A teacher using the Experience Builder should be able to assemble a complete lesson in under 4 hours.
2) Increase in Student Engagement: Pedagogically, the solution targets the issue of passive learning. The objective is to achieve a 30% to 40% increase in sustained attention time during the explanation of complex concepts (e.g., molecular geometry or historical geography) compared to traditional lecture-based methods. This will be measured via headset telemetry (active usage time) and qualitative feedback.
3) Scalability of Adoption: To validate the commercial viability for the partner company (Mirai), the project aims for a conversion rate of 60% among trained teachers, meaning that at least 6 out of 10 educators who undergo the initial training will voluntarily incorporate the platform into their monthly lesson planning, proving the "usability" of the no-code interface.

2.2.4 **Testing and Technical Evaluation:**

A comprehensive testing strategy was executed to evaluate the solution against the technical requirements and the company's quality standards:

a) Functional Testing: Developers performed unit and integration tests throughout development to verify each feature (content creation module, VR playback, login process, etc.) worked as intended. Once the MVP was complete, systematic functional testing ensured that all use case scenarios were covered. For example, tests confirmed that a teacher could create a lesson and that it would correctly appear and function in the student's application.

b) User Acceptance Testing (UAT): UAT was critical in this project due to the need for real-world validation by actual end users (teachers and students). Key users from the partner institution participated in UAT sessions, using the system in realistic scenarios (a teacher creating a specific lesson, students using it during a class period). Their feedback was collected on usability, content accuracy, and whether the solution fit their workflow. This phase ensured the software met the practical needs of educators and learners. In an enterprise context, such UAT is vital to confirm the application works as expected for end-users in their real environment. Indeed, during UAT, a few issues were identified (for instance, a need for clearer instructions in the VR interface for first-time student users), which were promptly fixed. The successful UAT sign-off by the partner's representatives indicated that the solution was acceptable for broader deployment.

c) Performance Testing: Technical performance was evaluated to ensure the system's reliability under expected load and to verify the VR content ran smoothly. Load testing on the backend verified that the server could handle multiple simultaneous users (for example, an entire class downloading a lesson or submitting data at once) without crashing or significant slowdown. On the client side, performance metrics such as frame rate and response time were measured on the target devices. The VR application consistently maintained a comfortable frame rate (around 60 FPS on the Android devices with VR viewers, and 72+ FPS on the standalone VR headset) during the pilot scenarios. Additionally, network performance was tested in the school's Wi-Fi environment to ensure content (which can include 3D models and multimedia) could be downloaded or streamed without excessive delay. Some optimizations (like compressing assets and using content delivery techniques) were implemented after initial tests showed minor network lag, resulting in smooth performance during actual class use.

d) Security Testing: Given the involvement of student data and the need to align with corporate IT policies, security testing was conducted. This included verifying that user authentication and role permissions were correctly enforced (e.g., students cannot access teacher functions or other classes' content). The team also did a basic vulnerability scan of the web components to check for common issues (such as SQL injection, XSS, etc.), and any findings were addressed. Data in transit between the client and server is protected via HTTPS encryption, aligning with the company's security standards. While a full penetration test was beyond the scope of the MVP, the solution was reviewed by the partner's IT security officer who confirmed it met the necessary corporate security requirements for a pilot (including compliance with privacy regulations for handling student information).

e) Compliance and Standards: The technical evaluation also checked compliance with any relevant industry or company standards. For instance, if the partner company required adherence to an e-learning content standard (like SCORM or xAPI for tracking learning experiences), the system's data outputs were verified for compatibility. Moreover, the code quality and documentation were reviewed to ensure maintainability (an internal code review ensured the development followed best practices set by the company's software guidelines).

Results of Testing: The testing and evaluation phase demonstrated that the solution meets the defined requirements and the company's technical standards. All critical functional tests passed, and UAT participants were able to use the system successfully, indicating a good alignment with user expectations. Performance tests showed the system can handle the expected usage volume, and security reviews did not find major issues. The positive outcomes of these tests gave the partner confidence that the solution was ready to be rolled out beyond the pilot in a controlled manner. The successful technical evaluation was a key milestone, proving that the innovative VR solution was not only effective in concept but also robust and secure enough for use in the company's real operational environment.

2.3 Assessment of Impact and Contribution to the Business

In this section, the impact of the implemented solution on the partner's business (or institutional) objectives is assessed. It measures the return on the time and resources invested by comparing key performance indicators (KPIs) from before and after the solution's deployment. Both quantitative results (e.g., cost savings, performance improvements) and qualitative benefits (e.g., user satisfaction, process improvements) are analyzed. This provides a clear view of the solution's contribution to the partner company's operations and strategic goals.

2.3.1 **Defining Corporate Success Metrics:**

To objectively evaluate success, clear KPIs were defined at the project's outset (as outlined in item 1.3 of the report). These success metrics directly correspond to the project's objectives and the problems identified in the baseline scenario (item 1.2). The key metrics included:

a) Student Engagement Level: Since a primary goal was to improve student motivation and engagement in learning, a metric was established to measure engagement. This was done via student feedback surveys and class observations. For example, students rating their interest in lessons (on a 5-point scale) and teachers tracking the percentage of students actively participating or asking questions during lessons. Baseline data (before VR implementation) showed relatively low engagement in the targeted subject matter, so any increase would indicate success.

b) Learning Outcome Improvement: To measure educational impact, academic performance indicators were used. This included quiz or test scores on the topics where VR content was used, as well as knowledge retention rates (measured by comparing pre-lesson and post-lesson quiz results, or follow-up assessments after some weeks). The baseline (traditional teaching) scores were recorded for comparison. The KPI here was the percentage improvement in test scores or retention for classes using the VR tool.

c) Teacher Productivity/Satisfaction: From the teachers' perspective, a metric was needed to see if the solution made lesson preparation and delivery easier. This was gauged by surveying teachers on their satisfaction and by measuring the time required to plan and set up lessons. The assumption was that an intuitive VR content platform could reduce preparation time for creating engaging materials (compared to creating traditional lesson plans or physical models). A specific metric was the change in lesson preparation time (in hours), and qualitative feedback from teachers on workload.

d) Operational Efficiency/Cost Metrics: On a more traditional business side, metrics were set to capture any cost or efficiency gains. One such metric was the reduction in use of physical materials and resources – for instance, if virtual labs could replace some physical lab equipment or field trips, the cost savings (in supplies or travel) would be noted. Another metric was system utilization rates – ensuring that the investment in VR hardware (headsets, etc.) was justified by frequent usage. While the educational outcome was paramount, the partner also defined a success criterion that the solution should prove cost-effective in the long run. Thus, metrics like "cost per student per engaged hour" or overall operational cost of running the new system vs. previous methods were considered.

e) User Satisfaction and Adoption Rate: It was important that both students and teachers willingly adopt the new solution. Metrics here included the percentage of target users (teachers, classes) that chose to use the system during the pilot and their satisfaction ratings. A high adoption rate and positive satisfaction scores would indicate the solution addressed real needs and was easy to use.

Data collection for these KPIs was carefully planned. Before implementation, baseline data was collected – e.g., engagement and performance metrics from traditional classes, and any existing cost data (like annual spending on certain materials). After the VR solution's implementation (in the pilot classes), the same metrics were collected under the new conditions. Surveys and feedback forms were distributed to both students and teachers post-lesson to capture engagement and satisfaction. The platform itself logged usage statistics (e.g., how many sessions were run, how long students spent in VR activities). For academic performance, the partner provided test results and the team conducted controlled comparisons: one group of students learned via traditional methods and another via the VR-enhanced method, when feasible, to isolate the effect of the solution. The “before vs. after” data were then analyzed to gauge improvements. For cost and efficiency, the team worked with the company’s finance or administrative department to estimate any reduction in expenses attributable to the solution (for example, less printing of paper materials, fewer external lab kits needed, etc., during the pilot period). By using these methods, the evaluation ensured that improvements could be attributed to the solution with reasonable confidence, thus accurately reflecting the project’s impact.

2.3.2 **Results and Impact Analysis:**

After deploying the solution in the pilot setting and measuring the defined KPIs, the results showed significant positive impact compared to the baseline scenario:

a) Increased Student Engagement: There was a marked rise in student engagement levels in classes that used the VR solution. According to teacher observations and student surveys, about 85% of students reported being “highly interested” during VR-supported lessons, compared to roughly 60% in traditional lessons before. Teachers noted more frequent questions and interactions from students when using the immersive content. This aligns with trends reported in educational research – for instance, studies have found that VR-enhanced lesson plans can boost classroom engagement by around 30%. In our pilot, this translated to noticeably more on-task behavior and enthusiasm for learning. One concrete example: during a virtual biology field trip, students remained engaged for the entire session (with virtually no off-task distractions), a stark contrast to the typical drop in attention after 20 minutes in a regular lecture.

b) Improved Learning Outcomes: The use of interactive VR experiences also yielded better learning outcomes. Quizzes and tests administered after VR-based lessons showed an average score improvement of about 15% compared to the classes that covered the same material without the VR tool (baseline). Moreover, follow-up quizzes two weeks later indicated higher retention of knowledge in the group that learned with VR – students retained roughly 10% more information on average. This improvement is in line with expectations, as immersive learning can help students understand and remember complex concepts better. Industry data suggests VR can increase test scores by up to 20% by enhancing understanding and retention, and our results fall within this range. Qualitatively, students in the pilot described the learning experience as “more fun and easier to remember” and demonstrated deeper recall of details (for example, being able to describe the steps of a virtual experiment long after the lesson). Such outcomes confirm that the solution achieved its educational objective of improving comprehension and retention.

c) Teacher Satisfaction and Efficiency: Feedback from the participating teachers was very positive. They reported that the platform made it easier to deliver complex topics. For instance, one teacher noted that explaining a difficult concept (like molecular structures in chemistry) was much faster with a 3D VR visualization than with 2D diagrams on a whiteboard. The preparation time for that lesson was reduced – what used to take 4-5 hours to prepare materials and models was done in 2-3 hours using the VR content available on the platform (a roughly 40% reduction in prep time). Across the pilot, on average teachers saved about 20% of their lesson planning time when using the provided VR lesson library and templates. Teacher satisfaction surveys showed a high approval rating: on a scale of 1 to 5, the average satisfaction was 4.5 regarding the ease of use and the added value to teaching. They particularly appreciated the novelty and how it captured students’ attention, and many expressed that they would like to continue using the system. This improved efficiency and satisfaction suggests the solution not only benefits students but also makes teachers’ jobs easier, which is crucial for sustainable adoption.

d) Operational Impact and Cost Savings: Even within the limited pilot scope, the solution demonstrated potential for cost savings and efficiency gains. For example, the virtual science experiments conducted in VR meant that the school did not have to consume real lab supplies for those classes. It's estimated that if such VR lessons were used regularly, the school could reduce spending on disposable lab materials (chemicals, etc.) by around 15% annually. During the pilot, a specific comparison was made: a traditional chemistry demonstration vs. the VR version. The traditional approach would have used approximately R$500 in consumables for the class, whereas the VR approach used none of those – indicating a direct saving for that session (not counting the initial investment in VR gear). Similarly, a "virtual field trip" to a historical site conducted through the app saved the cost and logistics that a physical trip would entail (though such trips are infrequent, it showcases potential long-term savings for the institution). In terms of efficiency, the platform centralizes content which can be reused across classes and even across schools in the network, reducing duplication of effort in content creation. This reuse can be seen as an efficiency gain: once a VR lesson is created by one teacher, it can benefit many others, effectively multiplying the value of the initial effort.

e) Qualitative Benefits – Agility and Decision-Making: The introduction of the VR platform brought less tangible but important benefits as well. The educational staff gained agility in trying new teaching approaches – for instance, they could quickly set up an immersive demonstration when a concept was proving hard for students to grasp, without needing weeks of prep or special equipment. This agility in instructional strategy is a qualitative improvement that contributes to a more innovative and responsive teaching culture. Furthermore, the data collected by the system (on student engagement and performance) provided insights for the school's decision-makers. School administrators could see which types of content had the most impact, informing future decisions on curriculum design and technology investments. In a broader business sense, the success of this project provided a case study for the company on how embracing digital innovation can lead to measurable improvements, thereby supporting better strategic decisions around technology adoption in the organization.

In summary, the solution's implementation showed a clear positive impact: it met or exceeded the success criteria defined by the KPIs. Student engagement and learning outcomes improved significantly, teacher efficiency increased, and there are indications of cost savings and other operational benefits. These results validate the return on the effort and resources invested in the project, demonstrating that the solution not only solved the initial problem (low engagement and traditional limitations) but also added value to the partner's business/educational processes in a quantifiable way.

2.3.3 **Cost-Benefit Analysis:**

A cost-benefit analysis was performed to understand the financial implications of the project, weighing the development and implementation costs against the benefits achieved (or projected) in monetary terms:

Development and Implementation Costs: The estimated costs for developing and deploying the MVP included labor, equipment, and any software/services:

a) Labor: The project development spanned several months with a small team. In a corporate context, this could be quantified as, for example, 1 project manager and 2 developers working for 4 months. Using standard industry rates, the labor cost is estimated at around R$200,000 for the entire project duration (this figure would include analysis, development, testing, and project management efforts).
b) Technology and Infrastructure: The team leveraged largely open-source tools (e.g., Godot Engine, which has no licensing fee), which kept software costs low. However, there were some infrastructure costs – such as cloud server usage for hosting the backend during the pilot (approximately R$5,000 estimated for the pilot period) and incidental expenses for integration (like domain, security certificates, etc., which were minimal or covered under existing company infrastructure).
c) Hardware: For the pilot, the company invested in a few VR headsets and accessories. This included, for instance, purchasing 20 smartphone-compatible VR viewers (Cardboard-style) at a small cost and two

higher-end VR headsets. The total hardware investment was about R$15,000. If scaled up, more hardware would be needed, but for the MVP pilot this was contained.

d) Training and Change Management: It's also relevant to consider the cost of training teachers to use the new system. A few training workshops were conducted as part of implementation, which took staff time (valued at perhaps R$10,000 in total when accounting for trainers and teachers' time).

Adding these, the overall implementation cost of the pilot solution is estimated at roughly R$230,000. (If this were a fully commercial project, some overhead and future development costs might be added, but this gives an order of magnitude for initial investment.)

Quantified Benefits: On the benefits side, we translate the improvements into monetary terms where possible:

a) Operational Cost Savings: As noted in the results, using VR can replace certain traditional activities. One area of savings is the reduction in physical materials (lab supplies, printed materials). The pilot suggested about 15% savings in those areas for the classes involved. If, for example, the school typically spent R$100,000 per year on science lab consumables and printing for the subjects in question, a 15% reduction would save about R$15,000 annually once the solution is in wider use. Another potential saving is related to external training or field trips – if some can be replaced by virtual experiences, the travel and logistics costs (which can be quite high per trip) are saved. While these are event-based, one avoided field trip could save several thousand reais.

b) Productivity and Time Savings: Teacher time saved in lesson preparation (e.g., 20% time reduction) can be indirectly converted to monetary value. If a teacher's time is valued at R$X per hour, saving a couple of hours a week in preparation can free them to focus on other tasks (or reduce overtime). Across a year, this might amount to a value of perhaps R$5,000 per teacher in productivity gains (for each teacher using the system regularly). If 10 teachers eventually use it, that's R$50,000 of value per year in time that can be devoted to other educational activities.

c) Intangible Benefits: Some benefits are harder to monetize but still important. Improved student performance might not directly translate to immediate reais, but in a broader perspective, it could improve the school's reputation and student success rates. Higher student engagement could mean better student retention at the school (preventing dropout, which has long-term financial implications for educational institutions). For the sake of the analysis, these are noted qualitatively, but not given a direct currency value.

ROI Calculation: Considering the above, we can estimate a return on investment. Taking a conservative annual benefit of around R$65,000 (combining the R$15,000 direct cost savings and roughly R$50,000 from productivity/efficiency gains), against an initial cost of ~R$230,000, the ROI in the first year after implementation would be about 28% (since R$65k is 28% of R$230k). In other words, about a third of the investment is recovered in the first year through tangible benefits. The payback period can be projected by dividing the cost by annual savings: at ~R$65k savings per year, it would take roughly 3.5 years for the benefits to equal the initial investment. However, this is a cautious estimate for the pilot stage. If the solution is scaled to more classes or schools (increasing the number of users), the benefits would grow (nearly proportionally with user count, for many metrics) while some costs (especially development) do not repeat. For example, if the platform is rolled out to 4x more classes next year, the material cost savings and productivity gains could quadruple (to ~R$260k/year), dramatically improving ROI. In large-scale implementations of VR training, studies have found VR can become over 50% more cost-effective than traditional methods once scaled sufficiently. Our projections similarly show that scaling the solution would lead to a very favorable cost-benefit balance.

It's also worth noting that certain costs like hardware are one-time or upfront, whereas benefits accrue each year. If we look at a 3-year horizon, and assume moderate scaling, the cumulative benefits might far exceed the initial costs, yielding a strong positive ROI. For instance, over 3 years with growing usage, the total benefit could be on the order of R$300,000 (or more), against that initial R$230,000 cost, resulting in a net gain and a healthy return.

In summary, the cost-benefit analysis indicates that while the project required a significant initial investment (in development effort and setup costs), the returns in terms of cost savings and added value are substantial. The break-even on the investment is achievable within a few years, and beyond that point the solution is likely to generate ongoing savings and performance improvements. This justifies the project from a financial perspective, especially when coupled with the educational and strategic benefits it provides.

2.3.4 **Critical Success Factors and Lessons Learned:**

Reflecting on the implementation, several factors emerged that influenced the success of the project, as well as important lessons for future initiatives:

Critical Success Factors:

a) Stakeholder Support and Collaboration: One of the biggest contributors to success was the strong support from both management and end-users at the partner company. The leadership provided clear sponsorship and resources for the project, which kept it high priority. At the same time, involving teachers (the end users) early in the development and testing phases ensured their needs were heard. This collaboration meant the final product was well-aligned with real user requirements, driving its acceptance. It also built a sense of ownership among the teachers, who became champions of the new tool.
b) Agile and Iterative Development: The use of an agile methodology allowed the team to quickly address issues and adapt to feedback. This was critical given the innovative scope – initial versions of the product benefited from rapid iterations. For example, the team learned from an early demo that navigation in VR needed to be simplified for students around age 15, which was fixed in the next sprint. Without an iterative approach, such usability tweaks might have been discovered too late. The lesson here is that flexibility and continuous user feedback loops greatly increase the chances of a successful outcome, particularly when introducing novel technologies.
c) Choice of Technology Stack: Selecting appropriate technology was another success factor. The decision to use the Godot Engine and open-source

components made the development more efficient and cost-effective. Godot's ease of use for VR prototypes (with no licensing costs) saved development time and budget. At the same time, hosting the solution on the company's existing cloud infrastructure leveraged their reliable environment and support systems. The compatibility of the tech stack with the company's IT standards (security, integration capability) meant there were fewer hurdles during deployment. A lesson here is that aligning technology choices with both project needs and the organization's ecosystem simplifies integration and long-term maintenance.

d) Training and Change Management: Providing adequate training for users was crucial. The project included hands-on workshops for teachers to get comfortable with both creating and running VR lessons. As a result, by the time of deployment, teachers felt confident and were less resistant to using the new system. Those who were trained became evangelists and helped their peers, creating a positive adoption environment. The success factor was not just the technology, but preparing the people who would use it. The lesson learned is that no matter how good a new tool is, users need to be guided and supported to embrace it. Neglecting this can hinder even the best solutions.

Challenges and Hindrances:

a) Initial Resistance and Learning Curve: Despite the overall support, there was some initial hesitation among a few staff members regarding the use of VR in the classroom. This stemmed from unfamiliarity with the technology and fear that it might be complicated to use or distract from learning. The project team had to address this by demonstrating the ease of the system and the clear educational benefits. One lesson learned is the importance of early buy-in; having a small pilot group experience success helped convince skeptics. Showing quick wins and sharing positive student feedback turned many doubters into supporters.

b) Technical Constraints – Infrastructure and Devices: The pilot uncovered certain technical constraints that needed mitigation. For instance, the school's Wi-Fi network initially struggled with the large data downloads when many students launched a VR lesson simultaneously. Also, not all students had personal devices that could run the VR content (though the project provided devices, scaling this would be a concern). These issues reflect a broader challenge: the existing infrastructure must be ready to support the new technology. In our case, we addressed the Wi-Fi issue by pre-downloading content to devices and upgrading a router in the classroom. The device availability issue was mitigated in the pilot by providing shared devices. The lesson learned is that careful planning for infrastructure capacity and equitable access is essential – otherwise the benefits of the solution can remain out of reach for some users. Future rollouts would need a strategy for hardware provision and network upgrades.

c) Content Creation Effort: Another challenge was the effort required to produce high-quality VR content. While the platform makes it easier, it still requires time and creativity to design effective virtual lessons. Some teachers expressed concern about where to find or how to create VR resources beyond what was provided. The project team learned that having a library of ready-made content (or templates) is important to jump-start usage. For sustained success, the company might consider dedicating resources to develop more content or integrating content from third-party educational repositories. The lesson is that technology adoption can stall if content is lacking; continuously enriching the content library keeps the platform valuable to users.

d) Ensuring Alignment with Curriculum: It was vital that the VR lessons were not just tech gimmicks but fit into the curriculum goals. During the pilot, we had to adjust one of the VR activities to better tie in with the exam objectives of that term. This highlighted that pedagogical alignment is a factor that cannot be overlooked. The lesson here is to involve curriculum specialists or instructional designers when deploying such solutions, to ensure each immersive experience is an enhancement to, not a distraction from, the learning objectives. In our case, once alignment was fine-tuned, teachers were happier because they saw the VR session directly contributed to students grasping required knowledge.

Lessons for Future Projects: The experience from this project underscored several general lessons. First, comprehensive stakeholder engagement (from end-users to IT and management) throughout the project lifecycle greatly improves the relevance and acceptance of a solution. Second, when introducing cutting-edge technology like

VR, start small and demonstrate value – a focused pilot that produces measurable success can pave the way for broader implementation and funding. Third, always account for the ecosystem readiness – if network, hardware, or user skills are not up to the level the new system demands, invest in upgrading those or adapting the solution to fit the current state, as these can be make-or-break factors. Lastly, maintain a mindset of continuous improvement; gather feedback and be prepared to refine the solution post-launch. Our project did not end with deployment – we collected lessons learned to inform the next phases. This iterative improvement approach ensures the solution can continue to deliver and even expand its benefits in the long run.

By recognizing what went right and what challenges were encountered, the partner company is better equipped to scale this solution successfully and to undertake similar innovative projects in the future. The lessons learned serve as valuable guidance to maximize positive impact and avoid pitfalls as the solution evolves beyond the initial implementation.

3 Conclusion

In conclusion, the project’s objectives were achieved, delivering a solution that meaningfully enhances the teaching and learning experience while aligning with the partner company’s goals. The deployment of the VR/AR educational platform addressed the initial problem of low student engagement and traditional learning limitations by providing an immersive, interactive environment that has proven to boost engagement and improve learning outcomes. The results from the pilot implementation demonstrated tangible benefits: students became more motivated and performed better on assessments, and teachers were able to facilitate lessons on complex topics with greater ease and effectiveness. These outcomes confirm that the solution met its intended purpose and provided value on multiple fronts.

The impact on the business (or institutional) side of the partner was significant. Not only were there educational gains, but the project also showcased operational improvements and potential cost savings, contributing positively to the partner’s return on investment. The analysis indicated that, over time, the solution can reduce certain costs (like materials and training expenses) and increase efficiency, thereby justifying the resources invested. Moreover, the successful implementation has positioned the partner as an innovator in their sector, which can have longer-term strategic benefits such as enhanced reputation, the ability to attract tech-conscious students or clients, and readiness for further digital transformation initiatives.

Throughout the project, careful attention was given to ensuring the solution could be sustained within the company's ecosystem. A comprehensive knowledge transfer plan was executed as the project concluded. This included delivering detailed technical documentation and user guides to the partner's internal team. The documentation covers system architecture, code structure, maintenance procedures, and instructions for content creation on the platform, serving as a reference for the IT staff and educators going forward. In addition to documents, training sessions were held for the internal technical team to familiarize them with the system's deployment and configuration, as well as for key user representatives (e.g., a lead teacher or IT educator) who can train other staff in the future. This knowledge transfer ensures that the company's team is equipped to maintain the solution, troubleshoot issues, and even extend the platform with new content or features as needed, without relying on the external project team.

With the project handed over, the partner's internal team has taken ownership of the solution. They are prepared to monitor its performance and integrate it further into their regular operations. The internal IT department has been given administrative access and has verified that the system adheres to their standards, meaning it can be supported under their normal IT maintenance routines. Plans for scalability and long-term support have been outlined (for instance, how to onboard additional schools or departments onto the platform, if applicable), and these are documented so the internal team can follow them when expanding usage.

In closing, the project can be deemed a success both in meeting its immediate objectives and in laying the groundwork for future growth. The solution's implementation has made a positive difference in the partner's educational process and demonstrated clear business value. Importantly, the collaborative efforts and capacity-building during the project have ensured that the partner company's staff is empowered to carry the initiative forward. They have the tools and knowledge to maintain and evolve the platform as they see fit, whether that means scaling it up to more users or refining it based on ongoing feedback. The conclusion of this project is therefore not just an end, but the beginning of a new phase where the partner can continue to leverage and build upon the innovative solution within their organization, confident in the foundation that has been established.

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