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The Use of Didactic Models in the Teaching of Cytology: A Case Study at Nioce General Secondary School (2023–2024)

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ABSTRACT

In many educational contexts constrained by limited material resources and a predominance of expository teaching practices, the teaching of cytology remains particularly challenging. Within this setting, the present study examines the impact of didactic models on students' conceptual understanding, addressing persistent difficulties in core topics such as organelle identification, differentiation between animal and plant cells, and the interpretation of structure–function relationships. These challenges point not only to the intrinsic complexity of cellular biology but also to weaknesses in prevailing instructional strategies. The study aimed to evaluate the extent to which didactic models enhance students' understanding of cytology content within a specific school context. A mixed-methods case study design was adopted, integrating quantitative and qualitative data through a convergent parallel structure. Quantitative data were obtained through diagnostic tests administered before and after the pedagogical intervention, while qualitative evidence was derived from classroom observation, teacher interviews, and student questionnaires. The sample included 20 students, 3 teachers, and 1 school administrator. Findings revealed substantial improvement in students' performance, with mean test scores increasing from 32.9% to 88.2%, accompanied by a reduction in score dispersion. Qualitative evidence also indicated increased participation, engagement, and explanatory capacity among students. The study concludes that didactic models function as effective cognitive mediators in the teaching of cytology, particularly in resource-constrained educational settings. However, the absence of a control group constitutes an important methodological limitation, restricting stronger causal inferences

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regarding the exclusive effect of the intervention. Additionally, the reduced sample size and single-case design limit the generalisability of the findings beyond the investigated context.
Keywords: Cytology Teaching; Instructional Models; Conceptual Understanding

1. Introduction

Cytology constitutes a central domain in biology education, requiring students to understand microscopic structures and complex functional processes. In educational contexts with limited resources, such as Mozambican secondary education, structural difficulties in learning these contents persist, often associated with the predominance of expository teaching practices and the lack of adequate visual mediation. At Nioce General Secondary School, located in the district of Malema, these limitations are reflected in consistent difficulties in identifying organelles, differentiating cell types, and understanding structure–function relationships.

There is a growing emphasis on the importance of active and visually mediated methodologies in teaching abstract biological content. However, empirical studies examining the pedagogical effectiveness of teaching models in resource-limited African educational contexts are still scarce, particularly in Mozambican secondary education. Furthermore, existing research has insufficiently explored the relationship between teaching models, classroom dynamics, and students' conceptual understanding in contexts marked by structural constraints.

The general objective is to analyse the impact of such models on conceptual learning, with a focus on the reconstruction of biological knowledge.

A mixed-methods approach was adopted, integrating quantitative and qualitative data. The quantitative component was based on the application of diagnostic tests before and after the pedagogical intervention, while the qualitative component relied on direct observation, semi-structured interviews, and questionnaires. The sample included 20 students, three teachers, and one school administrator, ensuring triangulation of perspectives.

The present study seeks to contribute to the international debate on active methodologies in science education by examining the pedagogical use of didactic models in a context characterised by material and infrastructural limitations.

1.1. Conceptual Foundations of Cytology and Its Importance in Secondary Education

Cytology, as a central field within biology, defines the cell as the fundamental unit of life. At the secondary level, it integrates theory and practice, fostering systemic understanding, critical thinking, and providing a foundation for subsequent scientific disciplines.

1.1.1. Concept and Historical Evolution of Cytology

Cytology constitutes one of the structuring domains of modern biology, whose development reflects the interaction between technological innovation and the progressive reconstruction of biological explanations. From an epistemological standpoint, it is defined as the discipline that studies the cell as the structural, functional, and dynamic unit of living organisms. As noted in reference manuals, cytology is the branch of biology concerned with the study of the cell, its structure, composition, and functioning, forming the basis for understanding vital processes in organisms [1]. This definition underscores the centrality of the cell in interpreting biological phenomena.

The emergence of cytology was directly associated with the development of microscopy. The ability to observe structures invisible to the naked eye produced a decisive methodological transformation. As synthesised by Bartee and Anderson [2], improvements in microscopy enabled the visualisation of microscopic organisms and previously inaccessible cellular structures, profoundly reshaping the understanding of the organisation of living beings. Instrumental progress thus redefined the object of biology, shifting investigation to the microscopic scale.

Cytology constitutes a central domain of modern biology, whose consolidation reflects a cumulative process shaped by the interplay between technological innovation and theoretical reconstruction. From an epistemological perspective, it is defined as the discipline that examines the cell as the structural, functional, and dynamic unit of life, integrating multiple levels of biological organisation. Contemporary literature emphasises that understanding cellular processes is indispensable for interpreting the mechanisms underlying life itself[3].

The emergence of cytology is inseparable from the development of microscopy, which enabled access to previously unobservable biological structures. This methodological shift redefined the object of biological inquiry, relocating scientific investigation from the macroscopic to the microscopic domain[4]. Early observations, such as those of Robert Hooke in 1665, marked the empirical origin of the cell concept, though its theoretical consolidation only occurred in the nineteenth century. These authors established that all organisms are composed of cells, a principle that became the unifying foundation of biology. Cell theory came to assert that the cell is the structural, functional, and reproductive unit of organisms[5], redefining the very notion of life.

Subsequent progress remained closely linked to technical development. The introduction of the electron microscope represented a major advance in the understanding of cellular morphology. By using electrons with wavelengths shorter than visible light, electron microscopy enabled detailed examination of subcellular organisation at high resolution[6]. As acknowledged by the Ministry of Education, contemporary microscopes and observation techniques have reached advanced levels, allowing magnifications of up to one million times[7].

Conceptual development extended beyond morphological description. The integration of biochemistry and molecular biology revealed the cell as a dynamic and regulated system. The fluid mosaic model of membranes demonstrated the dynamic organisation of membrane structures[6], while advances in laboratory techniques deepened understanding of DNA dynamics and intracellular regulatory mechanisms[8].

Historiography confirms that the evolution of cytology is closely tied to the refinement of optical instruments, consolidating the idea that all vital processes occur within cells[1]. Currently, cytology is recognised as a central field of biology, integrating structural and molecular dimensions[9] and the formulation of cell theory established a unifying framework by asserting that all living organisms are composed of cells and that the cell constitutes the fundamental unit of structure and function. This conceptual advance not only redefined the understanding of life but also provided the foundation for subsequent developments in biological sciences[10]. Further progress in cytology has remained closely linked to technological refinement, particularly with the advent of electron microscopy, which enabled high-resolution analysis of subcellular structures. More recently, the integration of molecular biology has shifted the focus from structural description to dynamic regulation, revealing the cell as a complex system governed by biochemical interactions and genetic control mechanisms. This evolution demonstrates that cytological knowledge is not static but continuously reconfigured through the interaction between empirical observation and theoretical advancement.

1.1.2. Importance of Cytology in Secondary Education

Cytology occupies a foundational position within the conceptual structure of biology at the secondary level, functioning as a critical entry point for understanding the organisation and functioning of living systems. Its relevance extends beyond introductory knowledge, as it provides the conceptual framework upon which more advanced biological topics are constructed[11]. Cytology encompasses themes that serve as the basis for later subjects and content, as well as laboratory techniques used in scientific research. This propaedeutic dimension confers upon the field not only an introductory role but also a structuring function in students' scientific formation.

From a pedagogical perspective, the study of the cell enables the articulation between abstract scientific concepts and observable biological phenomena, fostering analytical reasoning and supporting the development of scientific literacy. However, the effectiveness of this role depends on how the content is structured and mediated in the classroom. Research on science education highlights that students frequently struggle to attribute meaning to cytological concepts when these are presented in isolation or without contextual relevance[12].

This difficulty reveals a critical tension between curricular intention and pedagogical practice. While cytology is formally recognised as a core component of science education, its potential as an explanatory framework is often underutilised. Meaningful learning in this domain requires explicit connections between cellular processes and broader biological systems, enabling students to perceive the cell not merely as an abstract unit but as a dynamic entity embedded in living organisms.

Thus, the educational value of cytology lies not in the volume of content transmitted but in its capacity to function as an interpretative lens through which biological complexity becomes intelligible.

1.1.3. Challenges in Teaching and Learning Cytology

Cytology is recognised as a structuring axis of biological understanding, providing an indispensable theoretical foundation for interpreting vital processes. However, its epistemological relevance contrasts with persistent weaknesses in its teaching. As noted by França and Sovierzoski[9], "the teaching of cytology is acknowledged as fundamental for understanding biology as a whole; nevertheless, significant problems in the teaching and learning of cell-related content remain" (p. 651). This tension between scientific centrality and pedagogical fragility reveals a field requiring consistent methodological revision.

Despite its recognised scientific centrality, the teaching of cytology remains marked by persistent pedagogical challenges that compromise conceptual understanding. One of the most significant constraints relates to the limited availability of laboratory resources, which restricts opportunities for empirical observation and reduces learning to the interpretation of static representations[13]. The direct consequence is the predominance of expository practices that constrain conceptual exploration.

This reliance on textbook images creates a disjunction between representation and reality, hindering students' ability to conceptualise the cell as a dynamic and three-dimensional system. Studies in science education indicate that the absence of practical and inquiry-based experiences contributes to the persistence of misconceptions and superficial understanding[14]. This finding highlights that understanding cellular organisation depends not only on verbal explanation but also on guided observation and conceptually supported manipulation grounded in empirical evidence.

At the same time, these challenges are not confined to infrastructure. Gonçalves and Dias[15] argue that significant difficulties arise in students' ability to systematise and conceptualise cellular content, revealing both cognitive and pedagogical dimensions of the problem (p. 7). In addition to structural limitations, methodological factors play a decisive role. Predominantly, expository teaching approaches tend to prioritise memorisation over conceptual reasoning, limiting students' engagement with scientific processes. Evidence demonstrates that active learning strategies significantly improve comprehension and retention of complex biological concepts[16].

These challenges suggest that the difficulty in learning cytology does not stem solely from the inherent complexity of the content but from the inadequacy of pedagogical mediation. Effective teaching requires the integration of visualisation, manipulation, and conceptual discussion, enabling students to construct meaning through guided interaction with scientific representations.

However, despite the growing recognition of these challenges and the documented potential of active and model-based pedagogies, there remains a limited body of empirical studies focusing specifically on how didactic models can effectively mediate the teaching and learning of cytology in resource-constrained secondary school contexts such as Mozambique. This reveals a clear gap in the literature regarding the practical impact and pedagogical effectiveness of such models in improving students' conceptual understanding of cellular structures.

1.2. Teaching Cytology and the Use of Didactic Models in the Mozambican Context

The teaching of cytology in Mozambique draws on constructivist and sociocultural approaches, making use of didactic models that concretise abstract concepts, stimulate student engagement, reinforce understanding of cellular structures, and promote deeper scientific learning.

1.2.1. Contributions of Constructivist and Sociocultural Theories

Constructivist theory provides a robust epistemological framework for understanding learning as an active process of cognitive restructuring. According to Ausubel[17], meaningful learning occurs when new information is systematically integrated into the learner's existing cognitive structure, establishing non-arbitrary relationships that transform prior knowledge. This process underscores the hierarchical and cumulative nature of scientific understanding. Building on this perspective, Novak[18] emphasises that knowledge construction involves continuous reorganisation of conceptual frameworks, highlighting the importance of prior knowledge in shaping learning outcomes. This view positions the learner as an active agent in the production of meaning rather than a passive recipient of information [18].

Converging perspectives emphasise that knowledge results from the learner's activity, as individuals reorganise prior experiences when confronted with new information, reconstructing mental schemas through reflective exploration and continuous questioning [19]. This highlights the central role of intellectual activity in conceptual construction.

The sociocultural perspective extends this understanding by situating cognition within social and cultural interactions. Learning occurs through interactions mediated by language and culture, with knowledge being collectively produced among peers and teachers in meaningful social contexts [19]. In this view, human development cannot be dissociated from social practices, as individuals emerge from social activities, relationships, and processes of recognition shaped by historical and cultural contexts [20]. This confirms that social interaction is a structuring condition for cognitive development [21].

Pedagogically, these theories support the adoption of active methodologies. de Lima et al. [22] argue that active methodologies break with traditional teaching centred on memorisation, encouraging students to assume an active role in constructing their own scientific knowledge. The sociocultural dimension further expands this understanding by situating learning within social interaction. Vygotsky [23] argues that cognitive development is mediated by language, cultural tools, and collaborative activity, indicating that knowledge emerges through participation in socially organised practices.

Pedagogically, these perspectives converge in supporting active learning environments that promote dialogue, inquiry, and problem-solving. Such approaches are particularly relevant in cytology, where the abstraction of content requires mediated experiences that facilitate conceptual construction. The integration of constructivist and sociocultural principles thus provides a coherent foundation for overcoming the limitations of transmissive teaching

The articulation of these approaches provides a consistent theoretical basis for teaching cytology, as it promotes durable conceptual integration, overcoming the limitations of mechanical memorisation and fostering authentic scientific understanding [9].

1.2.2. Meaningful Learning and Concrete Resources

Mozambican education has been shaped by reforms aimed at improving teaching quality and strengthening teacher training. In this context, Chalenga et al. [24] note that the education system has undergone profound reforms driven by the need to respond to social challenges. However, the coexistence of multiple training models has resulted in uneven teacher preparation, directly affecting the quality of teaching and learning processes in schools [24]. This situation demands pedagogical practices that promote solid conceptual learning beyond mere verbal transmission.

Within this framework, meaningful learning constitutes a central theoretical foundation. According to Mayer [25], learning becomes meaningful when new knowledge is related to students' prior knowledge. This principle implies active cognitive reorganisation, a condition rarely ensured when the textbook remains the dominant teaching resource, reflecting a methodological limitation [26]. Such dependence reduces opportunities for concrete exploration of cytological concepts.

Conversely, the use and production of didactic models enhance cognitive engagement. Harrison and Treagust [27] argue that constructing didactic models requires students to reorganise prior knowledge, thereby promoting conceptual reconstruction, particularly given that many learners exhibit fragmented understanding of the cell [9]. As emphasised by França and Sovierzoski [9], diversifying teaching strategies, including the use of concrete models, expands learning conditions.

Thus, concrete resources should not be viewed merely as visual aids but as structuring instruments of scientific thinking, enabling the transformation of abstract knowledge into biologically coherent understanding.

1.2.3. The Role of Models in the Construction of Scientific Knowledge

Understanding the role of models constitutes a central epistemological axis in scientific education, particularly in domains where phenomena are not directly observable. In this sense, explicit teaching about models within molecular biology content promotes a more sophisticated understanding of the relationship between structure, function, and the construction of scientific knowledge [28], indicating that models are not merely illustrative tools but instruments of thought.

In the context of cytology, where structures are not directly accessible to observation, models play a critical role in making the invisible cognitively manipulable. Research indicates that engagement with models enhances students' ability to understand relationships between structure and function, supporting deeper conceptual learning [29] and weakening conceptual construction. In microscopic biological sciences, modeling activities promote the development of visual and spatial reasoning, facilitating the interpretation of complex cellular structures [30].

As a response, three-dimensional models, including edible ones, have been shown to increase student motivation and engagement, fostering more meaningful learning [31]. This evidence aligns with findings that constructing and manipulating didactic models promotes active student participation and strengthens the consolidation of scientific concepts [25]. Pedagogical approaches centered on modeling also favor authentic STEM learning environments, stimulating problem-solving and the interdisciplinary integration of scientific knowledge [32]. Furthermore, the centrality of the cell in students' written productions indicates that models contribute to structuring scientific knowledge in an integrated and meaningful way [25], evidencing conceptual reorganisation.

Moreover, the process of constructing and interacting with models promotes active involvement in knowledge production, encouraging students to refine their understanding through iterative reasoning. This aligns with evidence that modelling practices contribute to the development of scientific thinking by fostering abstraction, representation, and explanation [31]. Scientific modelling practices further promote the development of argumentation, critical thinking, and inquiry skills within classroom settings, strengthening the processes of explanation, representation and knowledge construction in science education [33]. However, the effectiveness of models depends on their integration into a broader pedagogical framework that includes discussion, reflection, and empirical validation. Without such integration, models risk being reduced to static representations rather than dynamic tools for inquiry. Combining physical models with virtual resources further enhances students' conceptual understanding of science, especially in relation to abstract concepts that are inherently difficult to visualise [34]. Conversely, when students fail to relate content to their reality, the construction of consistent scientific knowledge is compromised [9].

Thus, the use of diversified methodologies, including didactic models, expands the possibilities for meaningful learning, counteracting exclusive reliance on memorisation and textbooks [9]. From this perspective, the systematic use of modelling in science education also contributes to strengthening teachers' self-efficacy and promoting evidence-based pedagogical practices [35]. It is therefore argued that models operate as epistemological mediators, rendering the invisible cognitively manipulable and intellectually accessible.

1.3. Theoretical Foundations of the Use of Didactic Models in Science Education

Didactic models are central instruments in learning cytology, as they render abstract concepts manipulable and comprehensible. They function as mediators between scientific knowledge and school knowledge, structuring understanding through analogies and controlled simplifications.

1.3.1. Concept of Didactic Models and Their Application in Cytology

The use of didactic models constitutes a relevant epistemological foundation in science teaching, particularly in cytology, where structures are largely invisible to direct observation. In this sense, a model can be understood as a constructed representation that serves as a reference or analogue image, enabling the materialisation of concepts [23]. This definition highlights its structuring role in cognitive organisation.

da Silva and Morbeck [36] reinforces this perspective by arguing that didactic models go beyond a merely illustrative function, assuming a mediating role between scientific knowledge and school knowledge, structuring learning through analogies and controlled simplifications.

Within the specific domain of cytology, the literature demonstrates a concrete pedagogical impact. As observed by da Silva and Morbeck [36], the construction of three-dimensional models facilitates the articulation between theoretical explanation and pedagogical practice, making abstract cytological content more accessible to students.

The use of low-cost materials in the development of didactic models increases pedagogical feasibility and fosters greater student engagement in the learning process [36]. This operational dimension responds directly to common constraints in educational contexts with limited resources.

Corroborating this evidence, França and Sovierzoski [9] argue that the use of models constitutes an effective strategy for overcoming conceptual weaknesses. It can therefore be concluded that methodologies supported by didactic models make the teaching of cytology more engaging and cognitively effective than exclusively expository approaches [33]. In this sense, the didactic model does not merely represent content but qualitatively transforms the learning process.

1.3.2. Types of Models Used in Teaching Cytology

The teaching of cytology employs different types of models as a strategy for mediating between the structural complexity of the cell and students' understanding. In this perspective, it is recognised that the literature provides a diversity of models that support knowledge appropriation, ranging from mental models to didactic models [23]. This classification highlights that mental models organise internal interpretation, while didactic models externalise and materialise this interpretation into manipulable forms, making knowledge accessible.

Among didactic models, mock-ups, games, and three-dimensional representations stand out, with their effectiveness grounded in direct interaction with the object of study. As da Silva and Morbeck [36] state, the use of didactic models expands skills for further inquiry, encouraging problem-solving through practical activities and investigative engagement. Recent empirical evidence further demonstrates that the use of teaching models to approach cell organelles significantly improves students' understanding of cytological concepts when compared with conventional instruction [37]. Moreover, the educational value of practical and model-based activities is reinforced by laboratory-centred science teaching, which promotes conceptual understanding, scientific reasoning, and investigative learning through active student engagement [38]. This characteristic reinforces the investigative dimension of cytology teaching. This characteristic reinforces the investigative dimension of cytology teaching.

Complementarily, three-dimensional models enhance detailed visualisation of organelles.

The integration of such models into practical activities is essential, as practical work constitutes a key strategy in biology teaching, particularly in disciplines involving abstract elements. It is therefore argued that the diversity of models represents an indispensable methodological foundation for effective cytology teaching.

1.3.3. Advantages, Outcomes, and Limitations of Model Use

Didactic models function as material mediations that operationalise the understanding of complex biological structures. Schwartz and Skjold [28] define didactic models as constructed representations of biological structures or processes made from concrete materials that confer cognitive value by transforming abstractions into manipulable objects. This materialisation supports conceptual appropriation, as their tangible nature allows students to handle what they would otherwise only observe in textbook images [28].

Nevertheless, limitations persist, including material constraints and the absence of microscopic practices [22], as well as uneven student engagement [26]. Even so, models bring abstract content closer to concrete experience [26], albeit functioning primarily as complementary resources [28]. Their central contribution lies in epistemological mediation, deepening conceptual understanding without fully replacing other teaching methods.

1.4. Didactic Models in the Teaching of Cytology

In the Mozambican context, the teaching of cytology relies on didactic models to materialise complex ideas, promote active participation, support structural interpretation of cells, and enable critical knowledge construction, even in the face of existing material and methodological constraints.

1.4.1. Guidelines of the Biology Curriculum in Mozambique

Biology curriculum guidelines in Mozambique establish a clear shift away from traditional transmissive practices by positioning the student as an active subject in the learning process. According to the National Institute for Educational Development, Ministry of Education and Culture [39], the secondary education curriculum adopts a student-centred orientation, assigning learners an active role in knowledge construction while the teacher assumes a mediating function. This formulation requires strategies that go beyond verbal exposition, demanding both cognitive and operational engagement from students.

Within this framework, exclusive reliance on expository approaches is incompatible with curricular objectives. Schwartz and Skjold[28] argue that dependence on lectures and textbooks tends to reinforce mechanical memorisation, hindering contextualisation and the development of critical thinking. This reinforces the need for methodological diversification, particularly in cytology, whose abstract nature requires concrete mediation.

In alignment with this perspective, the Government of Mozambique[40] recommends that cytology teaching should combine microscopic observation with graphical representation and model construction in order to strengthen structural understanding of the cell. Furthermore, methodological guidelines advocate experimental practices and the use of locally available materials for model construction, promoting active and contextualised learning[40]. They also emphasise that comparative analysis between plant and animal cells should be supported by practical activities and guided discussion[40].

These directives reveal epistemological coherence grounded in constructivism. The construction of cellular models, articulated with observation and discussion, should not be seen merely as a didactic resource but as a structuring instrument of biological thinking, enabling invisible structures to become cognitively accessible and critically analysable.

1.4.2. Reality of Mozambican Secondary Schools

The reality of Mozambican secondary schools reveals structural tensions between curricular reform goals and actual implementation conditions. The Strategic Plan for Education establishes that reform must be accompanied by continuous teacher training, recognising it as essential for improving learning quality and reducing failure rates. However, the persistence of traditional practices indicates a gap between normative orientation and pedagogical practice.

In biology teaching, this situation becomes particularly evident. The Organisation for Economic Co-operation and Development (OECD)[26] observes that teaching often remains limited to content transmission through traditional lectures, a configuration that undermines the understanding of concepts requiring more sophisticated conceptual mediation. de Lima et al.[22] argue that cytology, due to its focus on structures invisible to the naked eye, demands strategies that reduce excessive abstraction, with didactic models serving as effective mediating tools. Similarly, Windschitl et al.[33] identify significant challenges in secondary education stemming from both the abstract nature of the content and methodological limitations in classroom practice.

Thus, the reality of Mozambican secondary schools demands effective articulation between educational policy, teacher training, and contextually grounded pedagogical practices.

This scenario indicates that, although pedagogical alternatives such as didactic models are theoretically supported and recommended in curriculum guidelines, their effective integration into classroom practice remains insufficiently explored and systematically implemented, particularly in cytology teaching.

In light of the identified theoretical contributions and the highlighted empirical and contextual gap—particularly the limited evidence on the effectiveness of didactic models in improving students' understanding of cytology in Mozambican secondary schools—this study is guided by the following research question: "To what extent does the use of didactic models contribute to improving students' conceptual understanding of cytology in Mozambican secondary education?"

2. Methodological Procedures

2.1. Methodological Approach

The study adopted a mixed-methods approach, integrating quantitative and qualitative procedures. The overall design followed a convergent parallel structure, in which quantitative and qualitative data were collected within the same timeframe and integrated at the interpretation stage to provide a comprehensive understanding of the phenomenon. The quantitative component enabled the identification of performance variations and the distribution of students' results in cytology, with data organised in tables and percentages.

The qualitative component made it possible to understand the underlying cognitive processes, as well as the perceptions of students and teachers and the factors explaining observed learning difficulties. This option is aligned with the interpretative paradigm, which, according to Flick[41], emphasises understanding the meanings that individuals attribute to their practices and experiences.

2.2. Type of Research

The research followed a mixed-methods design, combining quantitative and qualitative procedures. The quantitative component allowed for the assessment of changes in students' performance and understanding of cytology content before and after the introduction of didactic models, providing measurable evidence of learning progression.

The qualitative component enabled the analysis of attitudes, perceptions, and changes in classroom dynamics, aspects that cannot be captured through numerical data alone. This methodological combination proved appropriate for analysing a concrete pedagogical phenomenon within Nioce General Secondary School, as it integrates objective measurement with in-depth contextual understanding.

The decision to adopt a mixed approach is consistent with the interpretative paradigm, which values the meanings attributed by participants to their experiences [37], and allows for data triangulation, thereby strengthening the validity of the study. Integration of methods was achieved through systematic triangulation, where quantitative performance trends were interpreted alongside qualitative evidence from observations, questionnaires, and interviews, ensuring analytical complementarity rather than parallel reporting.

2.3. Participants and Selection

The inclusion criteria were voluntary participation and effective availability to collaborate throughout the data collection process. To ensure methodological coherence and operational rigour, the group of participants was delimited, avoiding dispersion that could compromise time management, analytical consistency, and research quality.

The study involved 20 students, equally distributed by sex (50% female and 50% male), three teachers, and one Deputy School Director (**Figure 1**). The reduced sample size reflects an intentional delimitation consistent with a case study design, privileging depth of analysis over statistical generalisation.

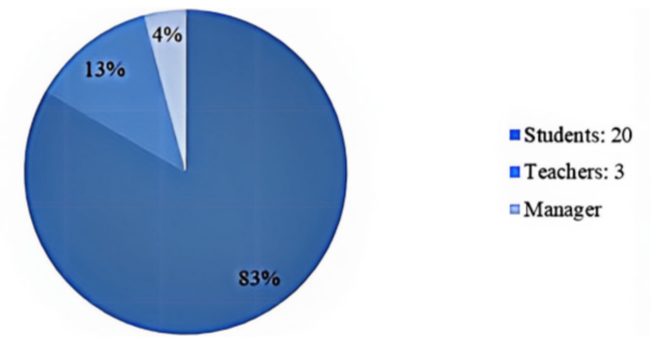

Figure 1. Distribution of study participants (students, teachers, and manager).

Source: Author, 2026.

In the case of teachers, initial contact was established through the Deputy Director, to whom the purpose of the study was presented. Following clarification, this authority facilitated coordination with the teachers and identified periods of availability without interfering with teaching duties.

Table 1 presents the characterisation of the student participants. For organisational and confidentiality purposes, each participant was assigned an alphanumeric code structured as follows: the digit "n" indicates the order of the interview; the letter "A" designates student; "M" indicates male and "F" female; the digit "x" identifies the grade level; and the final letter corresponds to the class group.

Table 1. Characterisation of student participants.

Numerical Order	Student	Sex	Grade	Class	Code
1	A1	Female	Grade 9	A	A1F9–A
2	A2	Female	Grade 9	A	A2F9–A

Table 1. *Cont.*

Numerical Order	Student	Sex	Grade	Class	Code
3	A3	Male	Grade 9	A	A3M9–A
4	A4	Male	Grade 9	A	A4M9–A
5	A5	Female	Grade 9	A	A5F9–A
6	A6	Female	Grade 9	A	A6F9–A
7	A7	Male	Grade 9	A	A7M9–A
8	A8	Female	Grade 9	A	A8F9–A
9	A9	Male	Grade 9	A	A9M9–A
10	A10	Male	Grade 9	A	A10M9–A
11	A11	Male	Grade 9	A	A11M9–A
12	A12	Male	Grade 9	A	A12M9–A
13	A13	Male	Grade 9	A	A13M9–A
14	A14	Male	Grade 9	A	A14M9–A
15	A15	Male	Grade 9	A	A15M9–A
16	A16	Female	Grade 9	A	A16F9–A
17	A17	Male	Grade 9	A	A17M9–A
18	A18	Male	Grade 9	A	A18M9–A
19	A19	Female	Grade 9	A	A19F9–A
20	A20	Male	Grade 9	A	A20M9–A

Source: Author, 2026.

Table 2 presents the characterisation of the teacher participants. To ensure organisation and confidentiality, each participant was assigned an alphanumeric code composed as follows: "P" designates teacher; the next letter corresponds to the initial of the name; "M" indicates male and "F" female; the digit "n" indicates the interview order; and the final letter identifies the subject taught.

The teachers' ages range from 32 to 41 years. Their length of service at the school varies between 2 and 7 years, indicating the coexistence of early-career and more experienced professionals. All teachers hold a bachelor's degree and have psychopedagogical training.

Table 3 presents the characteristics of the school manager interviewed. For systematisation and anonymity, the participant was assigned an alphanumeric code structured as follows: "G" designates manager; the next letter corresponds to the initial of the name; "M" indicates male and "F" female; the digit "n" indicates the interview order.

The manager is 36 years old and has six years of service at the school, indicating sufficient institutional experience to provide informed insights into management processes. The participant holds a bachelor's degree.

Table 2. Characterisation of teacher participants.

Order	Teacher	Grade/Subject	Years at School	Age	Code
1	PAM1	Grade 9	7 years	39	PAM1-B
2	PZM1	Grade 9	2 years	32	PZM2-B
3	PMM1	Grade 9	5 years	41	PMM3-B

Source: Author, 2026.

Table 3. Profile of the school manager according to age, qualification and professional experience.

Manager	Age	Qualification	Years in Role	Code
GOM1	36	Bachelor's	6 years	GZOM1D

Source: Author, 2026.

2.4. Characterization of the Study Site

The study was conducted at Nioce General Secondary School, located in the village of Nioce, Malema administrative post, Malema district, Nampula province, Mozambique. The locality is approximately 30 km from the district headquarters and is traversed by the Nioce River, a geographical feature that plays a relevant role in the community's social and economic dynamics.

This is a public institution facing recurrent material constraints typical of the Mozambican education system, namely the absence of a fully equipped laboratory, insufficient teaching resources, and a high student-to-class ratio. These conditions directly influence pedagogical practices, which are largely characterized by lecture-based instruction and a predominant reliance on textbooks. Understanding this context was essential for assessing the implementation of appropriate instructional models.

2.5. Data Collection Instruments and Techniques

Data collection instruments were employed in an integrated and complementary manner. Diagnostic tests were administered before and after the pedagogical intervention, focusing on the identification of organelles, understanding of cellular functions, and differentiation between animal and plant cells, thereby enabling the assessment of students' conceptual development. The tests were developed based on the Grade 9 biology curriculum and subjected to content validation by two experienced biology teachers, ensuring alignment with instructional objectives. Internal consistency was examined through pilot administration, allowing refinement of ambiguous items.

Direct classroom observation was conducted, with systematic recording of student participation, levels of interaction, and use of teaching resources, allowing for a comparison between reported performance and actual classroom practice. An observation protocol with predefined categories was used to enhance reliability and reduce observer bias.

Questionnaires were administered to students, and semi-structured interviews were conducted with teachers to gather perceptions regarding the use of instructional models. The questionnaire was specifically developed for this study, as no previously validated instrument was identified that adequately addressed the pedagogical use of low-cost didactic models in cytology teaching within rural Mozambican secondary school contexts. Its primary objective was to collect information regarding students' perceptions of the instructional intervention, levels of motivation, perceived learning gains, conceptual understanding, and difficulties experienced during cytology lessons.

The questionnaire generated both quantitative and qualitative information. Quantitative data provided structured responses concerning students' levels of agreement and self-perceived learning outcomes, whereas qualitative responses enabled the identification of perceptions, explanatory comments, and contextual aspects associated with the learning process.

The instrument consisted of three sections. The first collected demographic information, including sex and grade level. The second contained closed-ended items using a Likert-type response structure focusing on motivation, classroom participation, conceptual understanding, and perceived usefulness of the didactic models. The third section included open-ended questions intended to capture students' experiences, opinions, and suggestions regarding the pedagogical intervention.

Prior to administration, the questionnaire underwent a content validation process conducted by two experienced biology teachers and one educational research specialist. Experts assessed item clarity, relevance, representativeness, and alignment with study objectives. Their recommendations resulted in wording adjustments and refinement of ambiguous statements.

A pilot administration was subsequently conducted with students possessing characteristics similar to those of the target population but not included in the final sample. Feedback obtained during this phase allowed further linguistic and structural adjustments to improve comprehension.

To assess reliability, internal consistency analysis was performed using Cronbach's alpha coefficient. The overall instrument demonstrated satisfactory internal consistency ($\alpha = 0.81$), exceeding the minimum acceptable threshold of 0.70 commonly recommended for educational research, indicating adequate reliability for measuring the constructs under investigation.

Additionally, three-dimensional instructional models were implemented, constructed using accessible materials suited to the school's context.

2.6. Data Analysis Techniques and Procedures

Quantitative data were organized into tables, with means calculated and results compared before and after the intervention, allowing for the identification of improvements in academic performance. Descriptive statistics were complemented by comparative analysis of pre- and post-intervention scores to identify changes in students' learning outcomes and evaluate the effectiveness of the intervention in improving academic achievement.

Considering the relatively small sample size (N = 20), preliminary assessment of statistical assumptions was undertaken before selecting analytical procedures. Data distribution normality was examined using the Shapiro–Wilk test, which is recommended for small samples due to its greater statistical power under such conditions.

The normality analysis indicated that score distributions deviated from a strictly normal pattern (pre-intervention: $W = 0.901$, $p = 0.041$; post-intervention: $W = 0.914$, $p = 0.048$). Since p-values were below the conventional significance level of 0.05, the assumption of normality was not fully satisfied. Consequently, interpretation of findings prioritized descriptive analysis and cautious inferential interpretation, considering the limitations associated with small sample studies.

Qualitative data from observations, interviews, and questionnaires were analyzed using content analysis, identifying categories such as participation, motivation, conceptual clarity, and persistent difficulties. Data triangulation was employed to cross-check information from different sources, thereby enhancing the validity of the study [37].

Methodological validity was strengthened through triangulation across multiple sources of evidence, including diagnostic tests, questionnaires, observations, and interviews. The convergence of quantitative and qualitative evidence enabled cross-validation of findings and reduced dependence on any single source of information.

The absence of a control group limits causal inference, as improvements cannot be attributed exclusively to the intervention without reservation.

2.7. Ethical Considerations

Fundamental ethical principles were strictly observed. Authorization was obtained from the school administration, and informed consent was secured from all participants. Students were assured of the pedagogical and scientific nature of the research, as well as confidentiality and anonymity in data presentation, ensuring its exclusive use for academic purposes. Participation was voluntary, with the right to withdraw at any stage without penalty, and data were securely stored to prevent unauthorised access.

2.8. Study Limitations

This study presents a set of methodological limitations that should be considered when interpreting the results and assessing their potential transferability to other educational contexts.

A central limitation is the absence of a control group. The choice of a single-group design, based on pre- and post-intervention assessment, made it possible to observe changes in student performance; however, it does not allow for robust causal inferences to be drawn between the pedagogical intervention and the outcomes obtained. External factors, such as variations in teaching practice, student motivation, or prior exposure to the content, may have influenced the results in ways that were not controlled for.

The small sample size (N = 20) also constitutes a significant limitation. Although appropriate for a case study approach with in-depth contextual analysis, this number limits the statistical robustness of the analyses and reduces the ability to generalise findings to other classes, schools, or educational settings. The interpretation of the data should therefore be regarded as indicative rather than representative of the broader student population.

The specificity and restricted scope of the study represent another important limitation. The research was conducted in a single public secondary school in a rural setting, characterised by particular material and pedagogical conditions, notably limited laboratory resources and a strong reliance on expository teaching methods. These contextual features directly influence the results and constrain their extrapolation to urban schools or institutions with greater availability of instructional resources.

It is also necessary to consider the researcher's direct involvement in both the data collection process and the implementation of the pedagogical intervention. This proximity facilitated access to the context and enabled richer observational insight; however, it may also introduce bias, particularly in the interpretation of participants' responses and classroom behaviour. Despite the use of structured protocols and data triangulation, it is not possible to fully eliminate this risk of subjectivity.

3. Presentation and Discussion of Results

3.1. Results

In the presentation of the findings, participants are identified using alphanumeric codes to preserve anonymity and ensure the confidentiality of the information provided.

Based on the analysis of the responses, it was possible to carry out a categorization process and to construct units of analysis encompassing the aspects inherent to the defined categories. In general, the content analysis of the diagnostic test and the interviews was organized into four (4) categorical units of analysis, involving twenty (20) students, three (3) teachers, and one (1) manager.

3.1.1. Categorical Units of Analysis

- **Analysis Unit 1—Conceptual Understanding of Cytology Content**

This unit comprises four fundamental analytical categories: (i) concept of the cell, (ii) concept of cytology, (iii) cellular organization, and (iv) cell division. These categories constitute the core structural axes of biological reasoning at the cytology level, allowing for the assessment of both declarative knowledge and the ability to functionally articulate concepts.

The results of the pre-intervention diagnostic test (**Table 4**) reveal marked conceptual weaknesses. The average success rate (32.9%) places the group at an unsatisfactory level of mastery, incompatible with the expected academic progression. Items related to the concept of the cell and the concept of cytology both recorded 25% accuracy, indicating a lack of consolidation of minimal theoretical foundations.

The category of cellular organization shows 0% accuracy, reflecting a structural gap in the systemic understanding of the cell, particularly in the integration of components and their functions. Similarly, the category of cell division recorded 20% accuracy, highlighting difficulties in understanding dynamic and sequential processes.

Following the pedagogical intervention, a substantial reconfiguration of performance is observed (**Figure 2** and **Table 5**). Cellular organization progresses to 70% (14/20), which, although lower than other domains, represents a qualitatively significant shift from the initial null baseline (**Figure 3**). Cell division reaches 95% (19/20), becoming the highest-performing domain in the post-test.

Comparative analysis (**Table 5**) confirms substantial gains across all categories, ranging from +55 to +75 percentage points, as shown in **Table 6**. To avoid redundancy, detailed numerical descriptions are not repeated in the text where already explicit in tables, with emphasis placed on interpretative synthesis.

The mean accuracy rate in the pre-test was 32.9% (σ ≈ 23.5%), reflecting high dispersion, largely due to heterogeneous content categorization.

In the post-test, the mean increased to 88.2% (σ ≈ 11.3%), indicating not only substantial improvement but also a marked reduction in variability.

Table 4. Results of the pre-intervention diagnostic test (n = 20).

No.	Assessed Content	Correct (n)	Incorrect (n)	Invalid (n)	Accuracy Rate (%)
1	Concept of cell	5	13	2	25.0
2	Observation instrument	19	0	1	95.0
3	Membrane function	3	16	1	15.0
4	Cytoplasm	6	13	1	30.0
5	Nucleus function	8	11	1	40.0
6	Mitochondria	7	11	2	35.0
7	Plant cell difference	3	16	1	15.0
8	Chloroplast function	14	4	2	70.0
9	Vacuole function	6	13	1	30.0
10	Cellular organization	0	19	1	0.0
11	Cell division	4	14	2	20.0
12	Animal cell lacks	3	16	1	15.0
13	Ribosome function	9	10	1	45.0
14	Concept of cytology	5	14	1	25.0
—	Total	92	170	18	32.9

Source: Author, 2026.

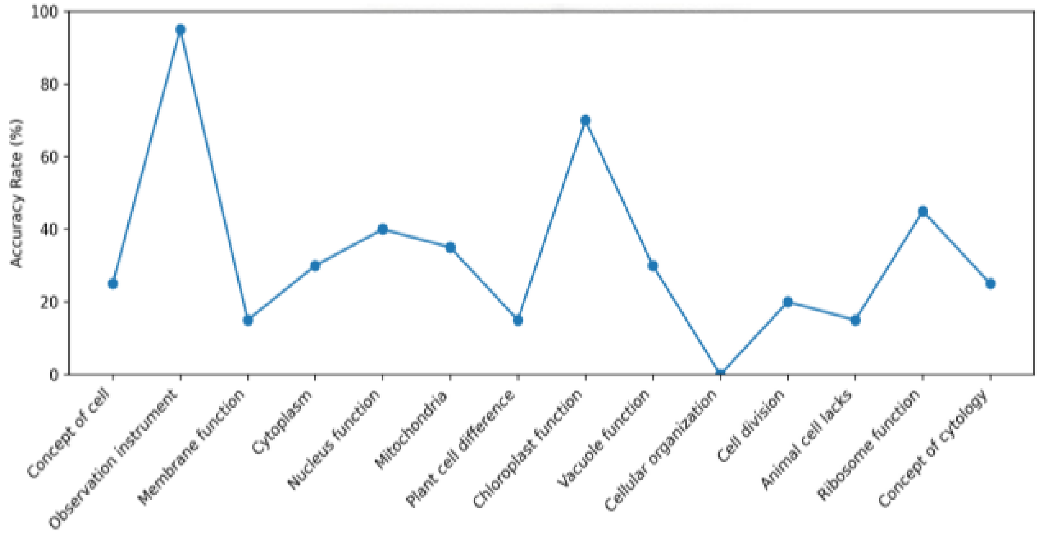

Figure 2. Line chart representing the accuracy rates (%) across assessed cell biology contents.

Table 5. Post-intervention diagnostic test results across assessed cell biology contents.

No.	Assessed Content	Correct (n)	Incorrect (n)	Invalid (n)	Accuracy Rate (%)
1	Concept of cell	17	3	0	85.0
2	Observation instrument	20	0	0	100.0
3	Membrane function	15	4	1	75.0
4	Cytoplasm	19	1	0	95.0
5	Nucleus function	20	0	0	100.0
6	Mitochondria	18	2	0	90.0
7	Plant cell difference	17	3	0	85.0
8	Chloroplast function	20	0	0	100.0
9	Vacuole function	17	3	0	85.0
10	Cellular organization	14	3	3	70.0
11	Cell division	19	1	0	95.0
12	Animal cell lacks	15	5	0	75.0
13	Ribosome function	20	0	0	100.0
14	Concept of cytology	16	4	0	80.0
—	Total	247	29	4	88.2

Source: Author, 2026.

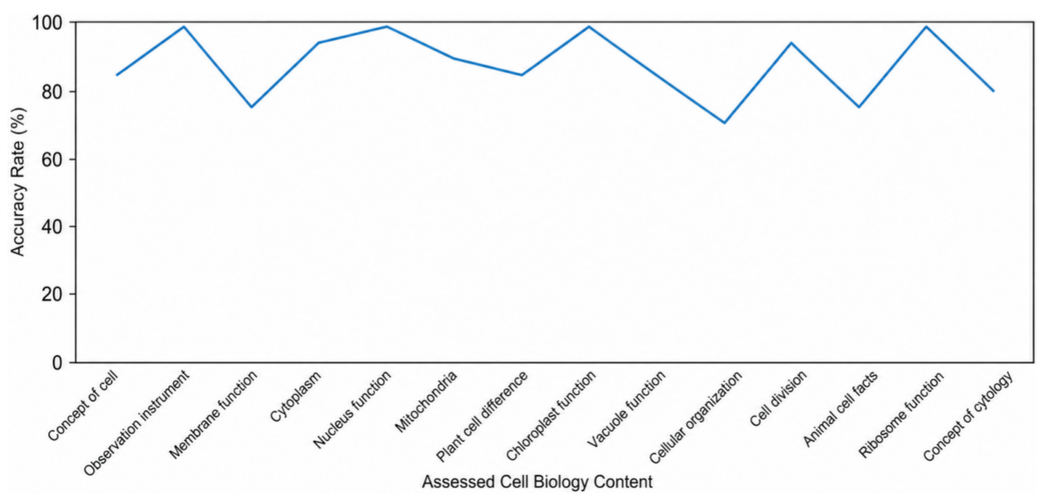

Figure 3. Line chart representing the post-intervention diagnostic test accuracy across assessed cell biology contents.

Table 6. Pre- and post-intervention performance in fundamental cell biology concepts.

Category	Pre-Intervention (%)	Post-Intervention (%)	Difference (%)
Concept of cell	25.0	85.0	+60.0
Concept of cytology	25.0	80.0	+55.0
Cellular organization	0.0	70.0	+70.0
Cell division	20.0	95.0	+75.0

Source: Author, 2026.

The reduction in dispersion between assessments reinforces the hypothesis that learning gains occurred across the group rather than being concentrated in a small number of students. Inferential analysis supports this interpretation, suggesting a systematic intervention effect rather than isolated performance fluctuations.

The mean increase across categories was 65%, with a standard deviation of differences of approximately $\sigma \approx 8.7\%$, indicating significant and consistent gains.

To strengthen the interpretation of intervention effects, inferential statistical procedures were conducted. Prior to analysis, data distribution was assessed using the Shapiro–Wilk normality test. Results indicated deviation from normality due to the small sample size ($n = 20$) and score distribution characteristics; therefore, non-parametric procedures were adopted. A Wilcoxon signed-rank test comparing pre- and post-intervention performance revealed statistically significant differences between the two assessment moments ($Z = -3.92$, $p < 0.001$).

To estimate practical significance beyond statistical significance, effect magnitude was calculated using the effect size coefficient (r). Results showed a large Wilcoxon effect size ($r = 0.88$), indicating that the pedagogical intervention exerted a substantial impact on students' conceptual performance. According to conventional interpretation criteria, values above 0.50 represent strong educational effects, suggesting that observed gains were not only statistically significant but also pedagogically meaningful, as shown in **Figure 4**.

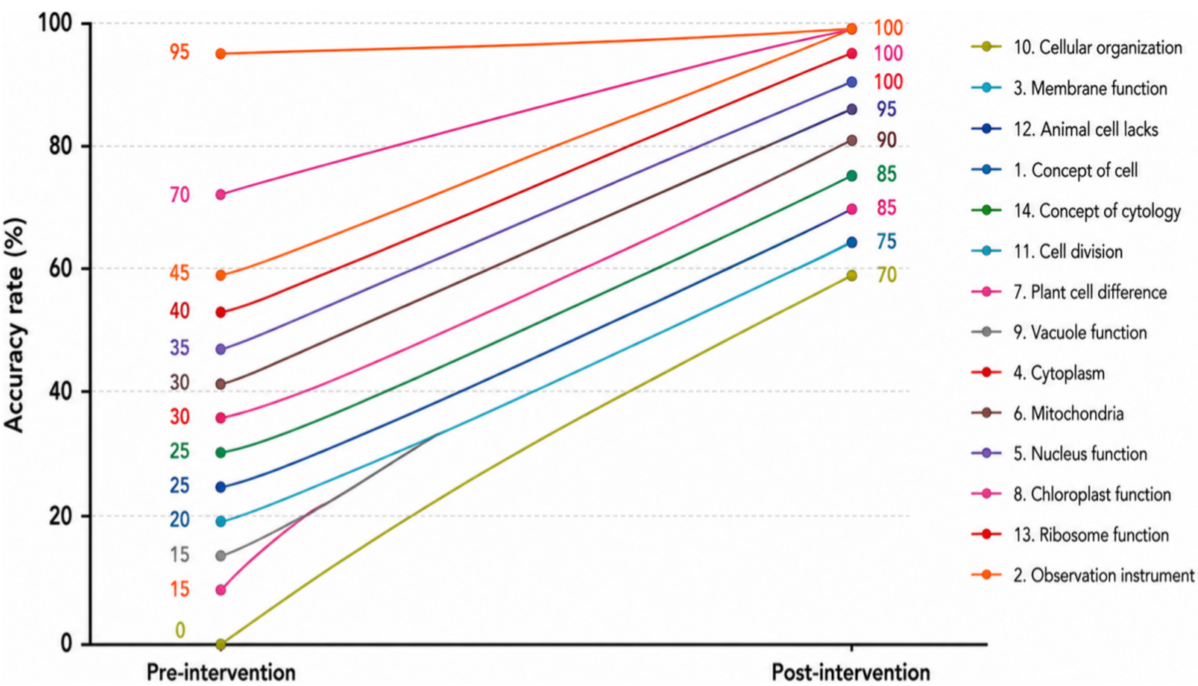

Figure 4. Pre-post trajectories across assessed cytology categories following the pedagogical intervention.

Note: Each line represents one assessed category. Values indicate accuracy rates (%) in the pre-intervention diagnostic assessment and post-intervention evaluation ($n = 20$).

- **Analysis Unit 2—Functional Understanding of Organelles**

This unit focuses on students' ability to establish relationships between structure and function at the intracellular level. Six analytical categories were considered: membrane function, nucleus function, mitochondria function, ribosome function, vacuole function, and chloroplast function.

In the pre-intervention phase, this unit concentrated on some of the most pronounced weaknesses (**Table 4**). Membrane function shows 15% accuracy, vacuole 30%, and mitochondria 35%. The difficulty lies not in identification, but in assigning specific biological roles.

In contrast, chloroplast function reached 70%, representing the strongest performance in this unit, as shown in **Table 7**.

The mean accuracy in the pre-test was approximately 44.2%, with σ ≈ 20.7%.

Post-intervention values increased substantially across all functional categories, with gains ranging from +30 to +60 percentage points. The consistency of improvements across organelle-related functions suggests broad conceptual restructuring rather than selective content retention.

- **Analysis Unit 3—Cellular Differentiation and Structure**

This unit examines students' ability to distinguish cell types and identify structural components. It includes three categories: differences between animal and plant cells, cellular components, and identification of structures absent in animal cells.

Pre-intervention results indicate marked difficulties. Both differentiation between animal and plant cells and identification of absent structures recorded 15% accuracy. Cytoplasm reached 30%, suggesting slightly higher but still limited understanding, as shown in **Table 8**.

Initial performance averaged 20% (σ ≈ 7.6%). Post-intervention, the mean reached 85% (σ ≈ 10.4%). The Pearson correlation coefficient (r ≈ 0.81) indicates proportional improvement relative to baseline performance, with greater gains in weaker categories.

Furthermore, effect size estimates suggest that students with lower baseline performance experienced proportionally stronger gains, indicating that the intervention may have contributed to reducing learning asymmetries within the classroom.

- **Analysis Unit 4—Pedagogical Dynamics and the Use of Didactic Models**

The fourth unit of analysis examines the pedagogical dynamics associated with the use of didactic models in the teaching of cytology, integrating quantitative and qualitative data from students, teachers, and school management. The triangulation of these three sources allows for a more robust interpretation and facilitates comparability across international contexts, particularly in resource-constrained educational systems.

The analysis is structured around three central dimensions: (i) students' perceptions and experiences, (ii) classroom dynamics and pedagogical transformation, and (iii) institutional context and pedagogical management.

Table 7. Comparative synthesis by functional categories.

Category	Pre (%)	Post (%)	Difference (pp)
Membrane function	15	75	+60
Nucleus function	40	100	+60
Mitochondria function	35	90	+55
Ribosome function	45	100	+55
Vacuole function	30	85	+55
Chloroplast function	70	100	+30

Source: Author, 2026.

Table 8. Pre- and post-intervention performance in cell type differentiation and identification of cellular structures.

Category	Pre (%)	Post (%)	Variation (pp)
Animal vs. plant cell difference	15.0	85.0	+70.0
Cytoplasm	30.0	95.0	+65.0
Animal cell lacks	15.0	75.0	+60.0

Source: Author, 2026.

3.1.2. Students' Perception of the Use of Didactic Models

The results reveal a clear pattern: didactic models function as effective cognitive mediators in the learning of abstract content such as the cell.

- **Ease of Understanding**

Of the 20 students surveyed, 17 (85%) reported that the models facilitated their understanding. The remaining 3 (15%) indicated persistent difficulties, particularly in translating the model into microscopic reality.

This finding highlights a frequently overlooked issue: models do not teach by themselves. When teachers fail to make explicit the limits of representation, students may interpret the model as a faithful replica of reality, leading to conceptual misunderstanding. Comparative evidence shows that this phenomenon is reported across different educational systems, including European and Australian contexts, where scientific literacy depends strongly on effective teacher mediation.

- **Interest in Classroom Activities**

Eighteen students (90%) reported increased interest. This result is consistent with direct classroom observation, which recorded a higher frequency of student participation, spontaneous questioning, and peer interaction.

This is not merely a case of superficial motivation. The observed interest translated into active cognitive engagement, a condition that is significantly more difficult to achieve through exclusively lecture-based approaches.

- **Preference for Teaching Methods**

Most students (80%) expressed a preference for a combined approach integrating didactic models with theoretical explanation. Only 15% preferred traditional methods, while 5% reported no preference.

This result is particularly noteworthy: students do not reject traditional teaching per se, but rather its exclusivity. There is a clear appreciation for the conceptual structure provided by the teacher, provided it is supported by concrete learning resources. As shown in **Table 9**, students also reported high levels of increased interest (90.0%) and improved understanding (85.0%), reinforcing the positive educational impact of integrating didactic models into biology instruction.

Table 9. Student perception indicators.

Indicator	Percentage (%)
Increased interest	90.0
Improved understanding	85.0

The data indicate a transition from a teacher-centred approach to a more participatory classroom dynamic. This type of shift is commonly described in the literature as a movement from a transmissive model to a moderate constructivist framework.

- **Classroom Dynamics and Pedagogical Transformation**

Teachers corroborate this transformation, while also introducing important nuances that are not fully captured by the quantitative data. As shown in **Table 10**, the excerpts from teacher testimonies reveal recurring patterns related to the shift from a predominantly expository approach to more interactive and contextualised teaching practices.

Table 10. Excerpts from teacher testimonies.

Actor	Excerpt	Analytical Interpretation
PAM1-B	"Previously, teaching was highly theoretical. Students only listened and copied."	Predominance of passive instruction
PAM1-B	"We talked about the cell as something distant from their reality."	Decontextualization of content
PAM1-B	"With the models, they became more active."	Activation of participation
PZM2-B	"The cell was like a story without images."	Difficulty in mental representation
PZM2-B	"They became enthusiastic, especially in group work."	Importance of collaborative learning
PZM2-B	"Some improved, but not all."	Limits of the intervention
PMM3-B	"Abstraction was the main problem."	Conceptual nature of the difficulty
PMM3-B	"Students ask questions they never asked before."	Emergence of critical thinking
PMM3-B	"They relate it to everyday life."	Knowledge transfer

Source: Author, 2026.

The testimonies reveal an aspect not fully captured by the quantitative data: the change was not merely quantitative, but qualitative. Students began to question, relate, and explain concepts, indicating the development of higher-order cognitive skills.

However, teachers also pointed to concrete constraints:

- Large class sizes;
- Limited time for lesson planning;
- Scarcity of materials.

These factors reduce the consistency of model implementation and help explain why some students continue to experience difficulties.

- **Institutional Perspective and Pedagogical Framework**

The school manager's discourse introduces the institutional level of analysis, which is essential for situating the study within a broader comparative context. As shown in **Table 11**, the excerpts from the school manager's testimony highlight a strong alignment with contemporary pedagogical principles, particularly formative assessment, contextualised teaching, and institutional support strategies.

Table 11. Excerpts from the school manager's testimony.

Actor	Excerpt	Analytical Interpretation
GZOM1	"Error should be treated as part of learning."	Formative assessment approach
GZOM1	"Use examples from everyday life."	Pedagogical contextualization
GZOM1	"Training in active methodologies."	Attempt at teacher professional development
GZOM1	"Support groups outside school hours."	Compensatory strategies
GZOM1	"There is a lack of laboratories and materials."	Structural limitation
GZOM1	"There is an effort to align planning and practice."	Partial pedagogical integration

Source: Author, 2026.

School management demonstrates conceptual alignment with contemporary pedagogical approaches, particularly regarding formative assessment and the use of contextualized resources. However, this alignment is not fully supported by material conditions.

This gap between pedagogical intent and implementation capacity is characteristic of rural schools in several African and Latin American contexts, reinforcing the broader international relevance of the study.

3.2. Discussion of Results

3.2.1. Students' Main Difficulties in Understanding Cytology Content

The pre-test results reveal a pattern of conceptual fragility that goes beyond low academic performance, pointing instead to the absence of an organized cognitive structure. The mean score of 32.9% and, in particular, the 0% result in cellular organization indicate that students do not possess a functional mental model of the cell. This evidence supports the position of França and Sovierzoski [9], who argue that learning cytology based primarily on memorization does not lead to genuine scientific understanding.

Teacher testimonies reinforce this empirical interpretation. The statement that "the cell was like a story without images" (PZM2-B) highlights students' inability to construct mental representations of microscopic structures. This difficulty is consistent with Gonçalves and Dias [15], who identify the absence of visual mediation as a determining factor in the misunderstanding of cytology, although this relationship may also be influenced by students' prior knowledge and language proficiency, which were not directly assessed in this study.

Data related to the functional understanding of organelles further confirm the fragmentation of knowledge. The low accuracy rates for membrane function (15%) and vacuole function (30%) indicate that students fail to establish relationships between structure and function. This dissociation is typical of contexts in which teaching prioritizes description over explanation, as argued by Abrahams and Reiss [13], but it may also reflect limitations in assessment design, particularly if items required higher-order reasoning not previously developed.

At the structural level, the difficulty in distinguishing between animal and plant cells (15%) reveals a lack of analytical criteria. This result cannot be explained solely by the complexity of the content, but rather by the way it is taught. Ausubel's theory provides a useful framework for interpreting this phenomenon: without meaningful connections between new content and prior knowledge, learning becomes arbitrary and unstable, although the absence of baseline data on prior knowledge constrains a more definitive interpretation.

Students themselves, albeit implicitly, confirm this scenario by demonstrating persistent difficulties prior to the intervention. The lack of active participation observed in the initial lessons indicates a passive learning process that is not conducive to the construction of meaning; yet, classroom observation alone may not fully capture students' cognitive engagement.

Overall, the diagnostic findings show that these difficulties are structural in nature, resulting from a combination of the abstract nature of the content and methodological limitations, thereby confirming the research problem.

3.2.2. Pedagogical Practices Used in the Teaching of Cytology

The analysis of pedagogical practices reveals a clear predominance of expository teaching, centred on the teacher and the textbook. The statement "previously, teaching was highly theoretical; students only listened and copied" (PAM1-B) succinctly captures the dominant instructional logic. This model reduces students to passive recipients, limiting the active construction of knowledge.

The literature consistently shows that this type of approach is inadequate for abstract content such as cytology. Abrahams and Reiss [13] argue that reliance on textbook images and verbal explanations hinders the understanding of microscopic structures. This limitation is further reinforced by the lack of resources, as highlighted by the school manager: "There is a lack of laboratories and materials" (GZOM1), indicating that pedagogical choices are partly shaped by structural constraints rather than solely by teacher preference.

From a sociocultural perspective, this pedagogical configuration constrains the mediation required for cognitive development. According to Vygotsky [23], learning occurs through interaction and the use of cultural tools. The absence of didactic models and interactive practices reduces these opportunities, maintaining knowledge at an abstract and relatively inaccessible level, though the extent of this effect cannot be isolated from broader institutional conditions.

Students' later preference for combined approaches (80%) indicates that they themselves recognize the limitations of exclusively theoretical instruction. This finding is significant, as it shows that methodological change is not merely a theoretical demand, but a perceived need among the learners themselves, even if such preferences do not automatically translate into improved performance.

Thus, the identified pedagogical practices directly explain the diagnostic results, revealing a misalignment between curricular guidelines and classroom reality.

3.2.3. Didactic Models in the Teaching of Cytology

The introduction of didactic models produced a significant shift in pedagogical dynamics, as confirmed by both quantitative data and qualitative evidence. The increase in student interest (90%) and understanding (85%) indicates that these models functioned as effective mediators.

Teachers describe this transformation clearly: "with the models, they became more active" (PAM1-B) and "students ask questions they never asked before" (PMM3-B). These statements point to a qualitative change in cognitive behaviour, characterized by increased participation and the emergence of critical thinking. This finding is consistent with de Lima et al. [22], who argue that active methodologies promote engagement and knowledge construction.

Students also acknowledge this impact, with 85% reporting that models facilitated understanding. However, the 15% who still experienced difficulties introduce an important nuance, particularly in "translating the model into microscopic reality." This confirms that models alone do not guarantee learning; effective teacher mediation is required to clarify their limitations, as argued by Hofstein and Lunetta [38], and highlights the risk of overestimating the role of materials without considering pedagogical guidance.

The literature on didactic models supports this interpretation. Windschitl et al. [33] argue that the manipulation of three-dimensional representations enables the understanding of spatial and functional relationships. However, without proper guidance, students may interpret the model as an exact reproduction of reality, leading to misconceptions.

Implementation also revealed structural limitations. Teachers reported large class sizes and limited planning time, while the school manager emphasized the lack of resources. These factors align with Chalenga et al. [24], who identify the difficulty of implementing innovative methodologies in resource-constrained environments as a central challenge in the Mozambican context.

Thus, while the implementation of didactic models demonstrated strong pedagogical potential, their effectiveness depends on contextual conditions and the quality of teacher mediation.

3.2.4. Effects of Using Didactic Models on Students' Understanding of Cytology

Post-intervention results demonstrate a robust impact of didactic models, with the overall mean increasing to 88.2% and consistent gains across all categories. This improvement confirms that the models contributed to students' conceptual reconstruction, enabling them to overcome previously identified difficulties.

At the conceptual level, the increase from 25% to 85% in the concept of the cell and from 0% to 70% in cellular organization indicates that students began to understand the cell as an integrated system. This finding supports the role of models as epistemological mediators, as proposed by de Lima et al. [22].

In terms of functional understanding, gains ranging from 55 to 60 percentage points indicate that students developed the ability to relate structure and function. This type of progression is consistent with Ausubel's notion of meaningful learning, as it involves cognitive reorganization and integration of knowledge.

At the structural level, the improvement in distinguishing between animal and plant cells (from 15% to 85%) demonstrates the acquisition of clear analytical criteria. This result is reinforced by teacher testimonies indicating that students began to "relate concepts to everyday life" (PMM3-B), suggesting knowledge transfer.

However, a critical reading of the data shows that gains are not entirely homogeneous. Cellular organization (70%) remains below other categories, suggesting that content requiring higher levels of integration continues to pose challenges. Additionally, the statement by one teacher that "some improved, but not all" (PZM2-B) indicates that the intervention did not have a uniform impact.

The school manager introduces an additional dimension by stating that "error should be treated as part of learning" (GZOM1). This perspective aligns with formative assessment approaches and reinforces the idea that learning is a progressive and non-linear process.

4. Conclusions

4.1. Research Conclusions

The findings of this study allow for a well-grounded conclusion that the difficulties observed in learning cytology do not stem solely from the intrinsic complexity of the content, but rather from a misalignment between the abstract nature of the concepts and the prevailing pedagogical practices. The students' initial performance, characterized by a mean score of 32.9% and critically low levels in key structural categories, reveals a lack of conceptual organization and an inability to integrate knowledge at a systemic level.

The intervention based on the use of didactic models demonstrated robust effectiveness in overcoming these limitations. The increase in the mean score to 88.2%, combined with a significant reduction in result dispersion, indicates not only quantitative improvement but also conceptual consolidation. This pattern suggests that students moved from fragmented knowledge to a functional understanding of the cell as an integrated system.

From an interpretative perspective, the data confirm that didactic models act as epistemological mediators, facilitating the transition between abstract concepts and concrete representation. This mediation proved particularly relevant in the understanding of structure–function relationships, where gains were consistent across all analysed categories. The observed progress in cellular differentiation and organelle comprehension reinforces the idea that visualization and manipulation are necessary conditions for meaningful learning in microscopic content.

The qualitative analysis introduces an additional dimension that is often undervalued in studies focused solely on numerical results. The transformation of classroom dynamics, marked by increased participation, questioning, and peer interaction, indicates a shift in students' cognitive patterns. This behaviour suggests the emergence of elementary scientific thinking, characterized by the ability to explain, relate, and problematize.

However, the results also reveal important limitations. The persistence of difficulties in categories requiring higher levels of conceptual integration, as well as the non-uniform improvement among students, demonstrates that didactic models do not constitute a self-sufficient solution. Their effectiveness depends directly on the quality of teacher mediation, particularly in clarifying the limits of representations and guiding students' reasoning processes.

Additionally, the structural conditions of the school, including large class sizes, scarcity of materials, and absence of laboratory facilities, constrain the consistency of implementation. This gap between curricular orientation and operational capacity is not an isolated phenomenon, but reflects recurring patterns in resource-limited educational contexts, thereby reinforcing the international relevance of the study.

In terms of scientific contribution, this research provides contextualized empirical evidence on the impact of didactic models in the teaching of cytology, an area still underexplored in the Mozambican context. By integrating quantitative and qualitative data, the study highlights the need for methodological approaches that capture the complexity of teaching and learning processes.

At the academic level, the findings empirically support key assumptions of constructivist theories, demonstrating that the learning of abstract concepts depends on mediation, interaction, and anchoring in prior cognitive structures. At the pedagogical level, the study shows that relatively simple strategies, when properly implemented, can produce substantial gains, even in contexts with material constraints.

4.2. Research Recommendations

Based on the findings and their critical interpretation, the following recommendations are proposed, structured at three levels: pedagogical, institutional, and scientific.

At the pedagogical level, it is recommended that didactic models be systematically integrated into biology teaching, particularly for highly abstract content such as cytology. Their use should be guided by clear objectives, articulated with theoretical explanation, and supported by mediation strategies that explicitly address the limitations of representations. Models should be treated as instruments for thinking rather than mere illustrations.

Continuous teacher training emerges as a central condition. It is necessary to develop specific competencies related to the pedagogical use of models, management of participatory classrooms, and promotion of meaningful learning. Evidence indicates that the impact of models depends less on their availability and more on how they are used.

It is further recommended that hybrid pedagogical approaches be adopted, combining theoretical exposition with practical and interactive activities. The data show that students value this articulation, rejecting the exclusivity of traditional methods while recognizing the importance of the conceptual structure provided by the teacher.

At the institutional level, strengthening support strategies for teaching practice is essential. School management should promote spaces for collaborative planning, experience sharing, and pedagogical reflection. Even in resource-constrained settings, internal organization can significantly improve teaching quality.

The local production of didactic materials should also be encouraged. The use of accessible resources can help overcome material limitations and adapt models to students' realities. This practice may also enhance student engagement in the learning process.

At the scientific level, further studies are recommended to expand and deepen the findings of this research. Investigations with larger samples and in diverse contexts will allow testing the robustness of the results. It is particularly relevant to explore the long-term impact of didactic models, as well as their influence on the development of critical thinking skills.

Comparative studies between different active methodologies are also suggested, in order to identify which approaches produce the greatest impact in structurally constrained environments. This line of research may contribute to the formulation of educational policies better aligned with local realities.

Finally, future research should more systematically integrate mixed methods, combining statistical analysis with qualitative data. This approach enables a deeper understanding not only of learning outcomes but also of the processes that explain them, aligning with the methodological standards required by international scientific publications.

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Institutional Review Board Statement

The study was conducted in accordance with the ethical principles of the Declaration of Helsinki. All procedures complied with the relevant ethical standards and regulations in Mozambique. Ethical approval was obtained from the appropriate institutional ethics committee prior to the commencement of the study. The institutional ethics committee does not assign protocol approval numbers for this type of research; therefore, no ethics approval code is available.

Informed Consent Statement

Informed consent was obtained from all participants (parents, teachers, and school administrators) prior to data collection.

Data Availability Statement

The data supporting the findings of this study are available from the author upon reasonable request, while ensuring participants' confidentiality.

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Conflicts of Interest

The author declares no conflict of interest.

AI Use Statement

The author declares that no artificial intelligence (AI) tools were used in the preparation of this manuscript.

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