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Research Article

Enhancing visualization skills and learning of mitosis in high school students: A research protocol using external representations

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ABSTRACT

External representations (ERs) have become increasingly prevalent in biology education. These visual aids can significantly enhance students' understanding of complex biological concepts, particularly those that are difficult to visualize, such as cellular processes and molecular interactions. The purpose of this research protocol is the systematic assessment of the pedagogical effectiveness of ERs in order to determine if they can reduce cognitive obstacles and cognitive load associated with understanding complex biological mechanisms as a methodological tool. Moreover, the research proposal aims to provide teachers with empirical evidence that will aid them in formulating specific teaching strategies aimed at improving the cognitive level and motivation of the trainees, as well as developing the visual and perceptual skills needed to apply biological phenomena effectively.

Keywords: external representations, visualization, mitosis, research protocol, students

INTRODUCTION

The utilization of animations or external representations (ERs) to facilitate the comprehension of biological phenomena in education has significantly increased over the past fifty years. These visual aids allow for the concretization of abstract biological concepts. In his cognitive theory of multimedia learning, Mayer (2014) states that "people learn deeper from words and pictures than from words alone." Consequently, the integration of ERs into biology education has experienced a substantial surge in the last half-century.

ERs refer to a specific semiotic process that is processed primarily through non-verbal, visual cognitive processes as described in dual coding theory. ERs include learning aids such as written text, diagrams, images, symbols, and animations, which are used to represent scientific phenomena for communication, teaching, learning, and research. In biology education, ERs are used to depict abstract biological phenomena that exist at the microscopic and molecular level, which otherwise could not be discerned with the naked eye. The improvement of students' visualization skills has also been supported by the decrease in the number of reported visualization difficulties associated with ER use. Previous research has shown, for example, that when learning with ERs, students may encounter reasoning difficulties that can jeopardize their conceptual understanding (Mnguni & Moyo, 2021; Veselinovska & Stavreva, 2021; Yakişan et al., 2013).

Based on the literature review, the effectiveness of using ERs generally depends on several factors, including the type of biological process depicted, the age of the students, the type of skills being acquired, and how ERs are integrated into teaching practices. It is also widely accepted that the choice of research methodology for investigating the effectiveness of ERs is influenced by the specific research question. For instance, if the goal is to determine whether ERs can enhance content comprehension, a controlled experiment would be suitable (Shaktawat & Menaria, 2018). Conversely, if the focus is on understanding how students use ERs to understand content, observational studies or student interviews would be more appropriate (Yakişan et al., 2013).

The use of ERs can be effective in improving content understanding and developing skills across all educational levels, from elementary to university. ERs can be used to present information in new and creative ways, help students organize and understand information, and provide a visual representation (VR) of concepts. However, the effectiveness of ERs can vary depending on the age and skills of the students. For example, elementary school students may have a greater need for VRs that are simple and easy to understand (Adri et al., 2020).

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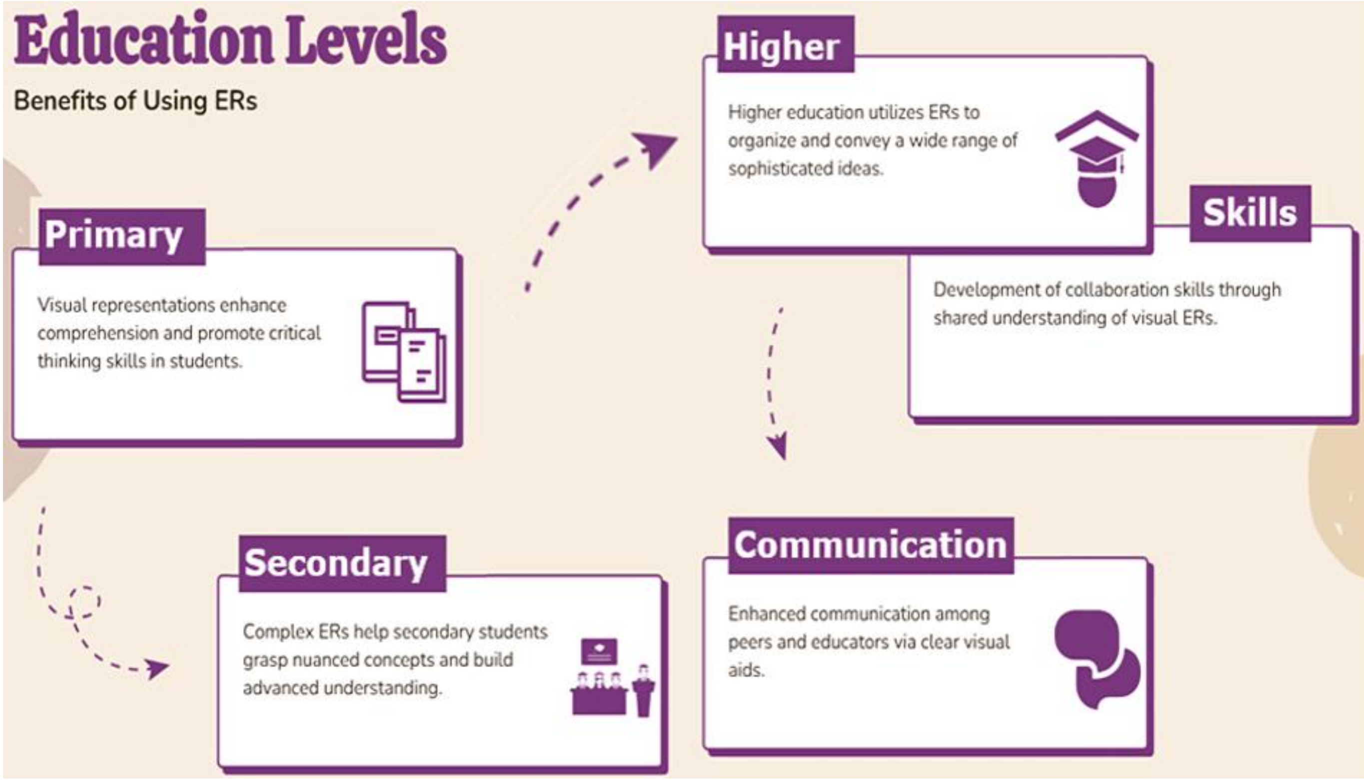

Figure 1. ERs are highly effective tools in education (they enhance understanding and strengthen communication abilities across all educational stages) (Source: Author's own elaboration)

Additionally, ERs can help elementary students develop skills such as critical thinking (thinking critically about the information presented to them), communication (communicating with their peers about their ideas), and collaboration (working with others to understand and learn new information). Middle and high school students may be able to understand more complex ERs (Hamzat et al., 2017; Rotbain et al., 2008).

Also, the use of ERs can be helpful for the university, as it can help students understand and learn new concepts. ERs can be used to present information in new and creative ways, help students organize and understand information, and provide a VR of concepts. In higher education, students are expected to confront a diverse range of ideas and concepts, many of which are intricate and necessitate profound comprehension. A study has demonstrated that the application of ERs in the realm of human anatomy enhances the comprehension of academic material. For example, students who used ERs to learn about the human system structure had better understanding of the concept compared to students who did not use ERs (Falvo, 2008; Hammuni et al., 2022; McClean et al., 2005; Peart et al., 2022).

In conclusion, lectures that utilize ERs lead to a more comprehensive understanding of certain concepts related to biological phenomena compared to lectures that employ only static visualizations. The increasing use of animated images and simulations is expected to have a positive impact on education. Educators can be encouraged to develop their own ERs or search online resources related to textbooks to find suitable ERs directly linked to the topics emphasized in the lecture (**Figure 1**).

This study aims to propose an innovative research protocol for implementing experiential pedagogical approaches using ERs. The objective is to enhance visualization skills and facilitate the learning process related to cell mitotic division, specifically targeting high school students (10^{th}-12^{th} grade).

MATERIALS AND METHODS

Research Hypotheses

ERs, such as diagrams, animations, and biological models, can serve as pedagogical tools to assist students in visualizing and comprehending complex biological phenomena, compared to textbook descriptions. For instance, a biological model of mitotic division in cells can help students understand how chromosomes are segregated during the process and how they may contribute to genetic diversity.

Assessment of the Limitations and Development of Strategies to Improve the Research Protocol

A comprehensive evaluation of the impact of VRs on students' visualization skills and the remediation of learning difficulties in mitosis necessitates the utilization of a broader spectrum of ERs pertaining to specific biological processes, such as the attachment of spindle microtubules to chromosome kinetochores and the segregation of sister chromatids. Furthermore, the establishment of specially designed classrooms for visually impaired students, equipped with adequate lighting, smooth surfaces, stable furniture, non-slip flooring, and specialized aids, would facilitate the accessibility and participation of these students in the learning process. The provision of support teachers would offer

Table 1. An analysis of the critical limitations of the research protocol and suggestions for specific improvement strategies

Limitation	Impacts	Proposed improvements
Limited range of VRs	Difficulty in assessing the impact of ERs on specific biological processes.	Expand the range of ERs to cover more biological processes.
Absence of specially designed classrooms for visually impaired students	Difficulty in accessing and participating in the learning process for visually impaired students.	Create specially designed classrooms with adequate lighting, smooth surfaces, stable furniture, and specialized aids.
Absence of support teachers	Reduced individualized support for students.	Provide specialized support from support teachers.
Differentiation of students' knowledge levels	Difficulty in assessing the impact of ERs on students with different knowledge levels.	Differentiate activities and materials according to students' knowledge levels.
Omission of questionnaire returns	Reduced reliability and validity of results.	Ensure collection of questionnaires by a teacher within the classroom.

individualized support, while the differentiation of students' knowledge levels regarding visualization techniques constitutes an additional factor to be considered.

Lastly, the omission of questionnaire returns constitutes a significant limitation, as questionnaires provide invaluable data for the analysis of results. To address this issue, it is imperative to ensure the presence of at least one educator in the classroom to collect student questionnaires and guarantee the completeness and accuracy of the collected data (**Table 1**).

Visualization Skills: A Qualitative Analysis Through Questionnaires

An anonymous interpretive questionnaire will be used as a measurement tool for the present research, which is proposed to be conducted on a sample of 100 students from the same grade but from different schools. This questionnaire will include both structured and open-ended questions, allowing the participating students to express their opinions without restriction (Mnguni, 2018). The primary objective of this research is to investigate students' visualization skills to better understand the factors that influence these skills and to identify possible ways to improve them.

Operational (& Theoretical) Definition Types of Research Protocol

The present protocol is proposed to be conducted in various educational institutions of the region, to obtain more reliable and representative outcomes. Visualization skills, which are essential for understanding and processing visual material, include identifying, interpreting, evaluating, and structuring visual data. In the context of the research, various variables are considered, such as demographic variables including the gender of the students and the school of origin (area). The independent variables represent the categories of these demographic characteristics, while the dependent variables are the students' responses to the diagnostic questionnaire. Through the study of these parameters, the research aspires to provide in-depth findings about students' visualization skills and the factors that influence them.

Participating Students

The research will focus on a sample of students from various regions of the prefecture. The sample will consist of 50 boys and 50 girls, ensuring balanced gender representation and providing more reliable and generalizable results. The selection of students is based on their common interest in life sciences, a field of vital importance for both health and the environment. This research protocol aims to examine and analyze the visualization skills of students, leveraging the dynamic educational experience in life sciences to enhance the learning process. Through the analysis of the data collected, it will be possible to conclude the educational practices that can support the development of these skills and promote scientific knowledge among young people (**Figure 2**).

Student Selection Process

In the present protocol, students will investigate the impact of animations or ERs on the understanding of biological phenomena, specifically mitosis, by conducting a sample survey in schools within the area. The reason for choosing this particular type of research is suggested because it is a popular method of social and educational research used to collect data from a subset of a population. A sample survey is generally recommended for studies because it can provide accurate results with much less cost and time and can be as accurate as the whole survey provided the sample is selected with proper strategy (Desnoyers & Rogiers, 2020; Mnguni & Moyo, 2021).

The organization of the sampling protocol is proposed to be completed in 4 phases (**Figure 3**).

1st phase

The selection of the study's objective is to investigate the extent to which ERs could be used to enhance students' visualization skills in order to reduce the learning difficulties associated with the complex biological processes of mitosis. The use of random sampling allows all statistical units (students) in the sampling frame (population) to have equal chances of being included in the study sample.

2nd phase

In this phase, a qualitative research approach will be determined, focusing on understanding the complex biological phenomena of mitosis through the visualization of ERs, about their description in the textbook. The data gathered during sampling shall be derived from the responses of students to a diagnostic questionnaire regarding the phenomenon of cell mitotic division and its distinct stages (dependent variable), considering the students' demographic factors (independent variables).

3rd phase

In this phase, during the process of organizing the sampling, procedures will take place that will allow for the selection, recording of results from the students, and

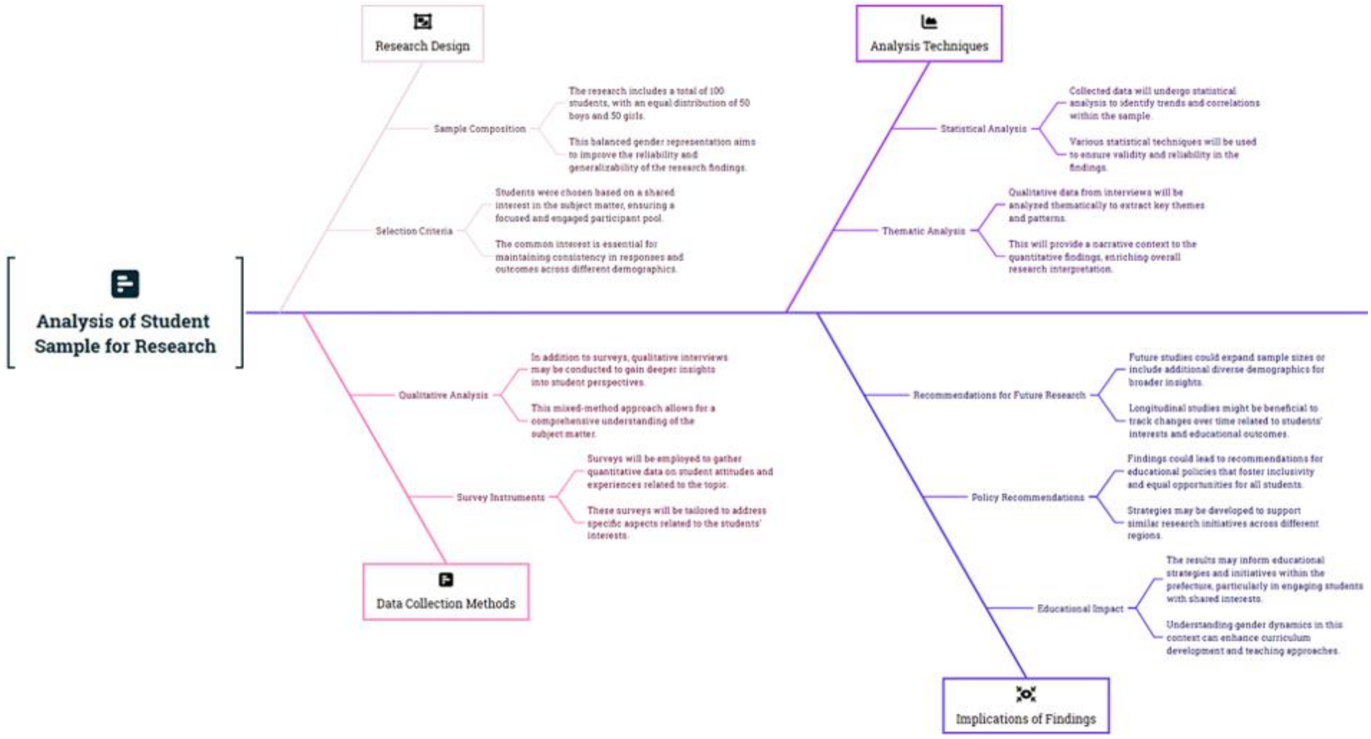

Figure 2. Research design, sample composition, data collection approaches, analysis methods, and implications (these elements form a framework for a cohesive research study) (Source: Author's own elaboration)

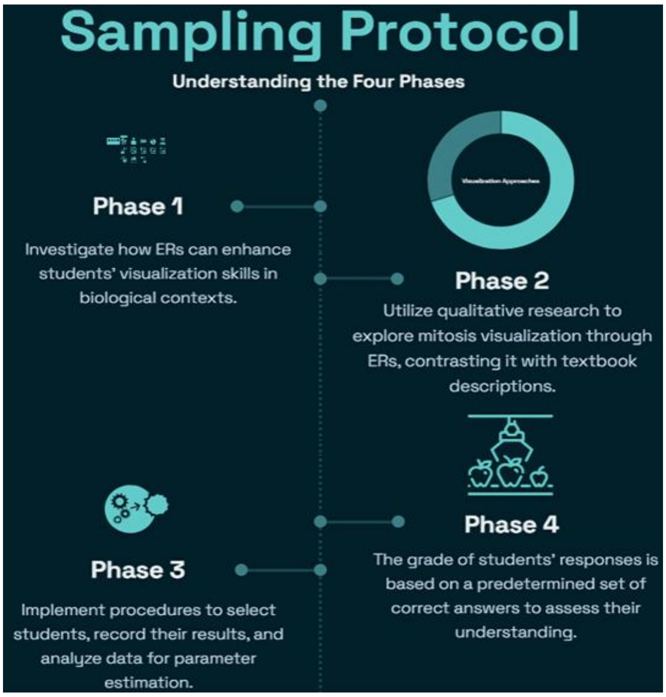

Figure 3. A four-phase protocol for assessing students' visualization skills (Source: Author's own elaboration)

subsequent analysis to estimate the parameters of interest. Specifically, the participating students will be randomly assigned to the control group and two experimental groups.

Subsequently, all three groups will be provided with self-study materials through which they can learn the basic introductory concepts of mitosis. These printed study materials will describe the biological process and its various stages using text, diagrams, and images. The learning outcome of this exercise will be that, by the end, the students will be able to define and describe the phenomenon of mitosis, explain its significance in organisms on our planet, discuss the characteristics of the various phases of mitosis, and identify the impact of mitotic cell division on the number and characteristics of the chromosomes in cells.

It is recommended that the study material be provided to the students for two days of work. The diagnostic evaluation questionnaire will then be administered to all participants as a pre-test after the two study days. One day before the exam, both groups will be given a lesson on the biological process of mitosis by the teacher. In the control group, no additional teaching and learning resources will be provided. The teacher will use the self-learning material for greater facilitation (presenting content, describing and explaining concepts, as well as solving problems with students) in the form of lectures. In the experimental group, ERs will be used to demonstrate the process of mitosis using animations as an additional teaching and learning resource. The animations to be used in the experimental group will be taken from open educational resources that will illustrate the process of mitosis graphically using various animated shapes, colors, on-screen text and narration. On-screen text will include captions for the various illustrations, while narration will explain the entire process. The teacher will facilitate the presentation of animated images by pausing and clarifying where he/she deems it appropriate and where the students ask for clarity and explanations. A post-test identical to the pre-test will be administered to participants in both groups one day after the lessons are taught through ERs.

4th phase

Students' responses will be graded against a set of correct answers. The scores obtained by the students will then be transformed into percentage scores to compare student performance. This is also consistent with the view that tests measuring variables such as ability can use interval or ratio scales where they "measure the same variable with equal intervals on the difficulty level" (Mnguni et al., 2016). Subsequently, all data will be analyzed quantitatively using the SPSS software package to determine the extent to which the animation could influence students' visualization skills related to basic introductory concepts of mitosis. The reason is that animation is the only variable that will be intentionally added to the experimental group.

Measurement Tools

As part of the research action design, the tool by Mnguni (2018) is suggested to be used as an assessment for understanding student's visualization skills.

This specific tool does not require prior biology knowledge from the students but will record the development of their skills related to visualizing the mitosis phenomenon. The questionnaire scoring, therefore, will focus on the degree to which visualization skills were demonstrated (**Table 2**).

The key axes around which questions could be structured for developing a new tool to explore students' visualization skills are, as follows:

1. Questions examining students' ability to explain and apply the principles of mitosis in specific cases. For example, students could be asked to explain how mitosis leads to an increase in the number of cells or how mitosis helps maintain genetic stability.
2. Questions assessing critical thinking and problem-solving skills. These could evaluate students' ability to use their knowledge of mitosis to solve problems or answer questions. For instance, students could be asked to explain what would happen to a cell if one of the mitosis stages was disrupted (**Table 3**).

Table 2. List of visualization skills that can be examined in the current research (Mnguni, 2018)

Skills	Definition
Analysis	• Identification of cellular components during mitosis • Determination of the exact number of chromosomes in the cell during mitosis
Description	• Description of the process of cell division • Definition of mitosis • Description of the phases of mitosis • Explanation of the significance of mitosis
Visualization	• Enumeration of the characteristics of anaphase • Enumeration of the characteristics of interphase • Enumeration of the characteristics of metaphase • Enumeration of the characteristics of prophase • Enumeration of the characteristics of telophase
Conclusion	• Calculation of the number of chromosomes at different stages of cell division
Outline	• Creation of the correct sequence of mitotic stages. • Description of the process of mitosis

Measurement Process (Data Collection Process)

The research is proposed to be conducted in a school after the relevant permission. It will occupy students and teachers for approximately two teaching hours. Informed consent is required from participating students and parents so that they fully understand the purpose, process, significance of participation, and the ability to withdraw. It is also necessary to ensure the anonymity of the participants and the absolute protection of personal data (**Figure 4**).

Table 3. Examples of multiple-choice, true-false, and comprehension questions that assess students' critical thinking and problem-solving abilities in addition to their capacity to explain and apply the concepts of mitosis (students' comprehension of mitosis and its significance for preserving genetic stability is evaluated using these questions)

Category	Question	Options
Multiple choice questions	-What does the M phase of the cell cycle represent?	(a) DNA replication (b) Cell division (c) Protein synthesis (d) Cell growth
	-Which of the following phases is NOT part of mitosis?	(a) Prophase (b) Metaphase (c) Cytokinesis (d) Anaphase
	-What occurs during prophase?	(a) Chromatin condenses into chromosomes (b) Chromosomes align at the equator (c) Sister chromatids are separated (d) The cell membrane reforms
	-The centrioles move to which part of the cell during mitosis?	(a) The equator (b) The center (c) The poles (d) The nucleus
	-In which phase do spindle fibers align chromosomes along the cell equator?	(a) Prophase (b) Metaphase (c) Anaphase (d) Telophase
True or false questions	-True or false: The M phase of the cell cycle includes both mitosis and cytokinesis.	True or false
	-True or false: Mitosis is completed in one single phase.	True or false
	-True or false: Prophase is the shortest phase of mitosis.	True or false
	-True or false: During metaphase, chromosomes line up along the equator of the cell.	True or false
	-True or false: Plant cells can pinch inwards during cytokinesis just like animal cells.	True or false
Comprehension questions	-What are the three phases that make up interphase in the cell cycle?	
	- Describe the process of chromatin condensation during prophase. What changes occur to the nucleolus at this stage?	
	-Explain the role of spindle fibers during metaphase. How do they contribute to chromosome alignment?	
	-During anaphase, what happens to the sister chromatids, and how are they referred to after separation?	
	-What is telophase, and what key events take place during this phase of mitosis?	

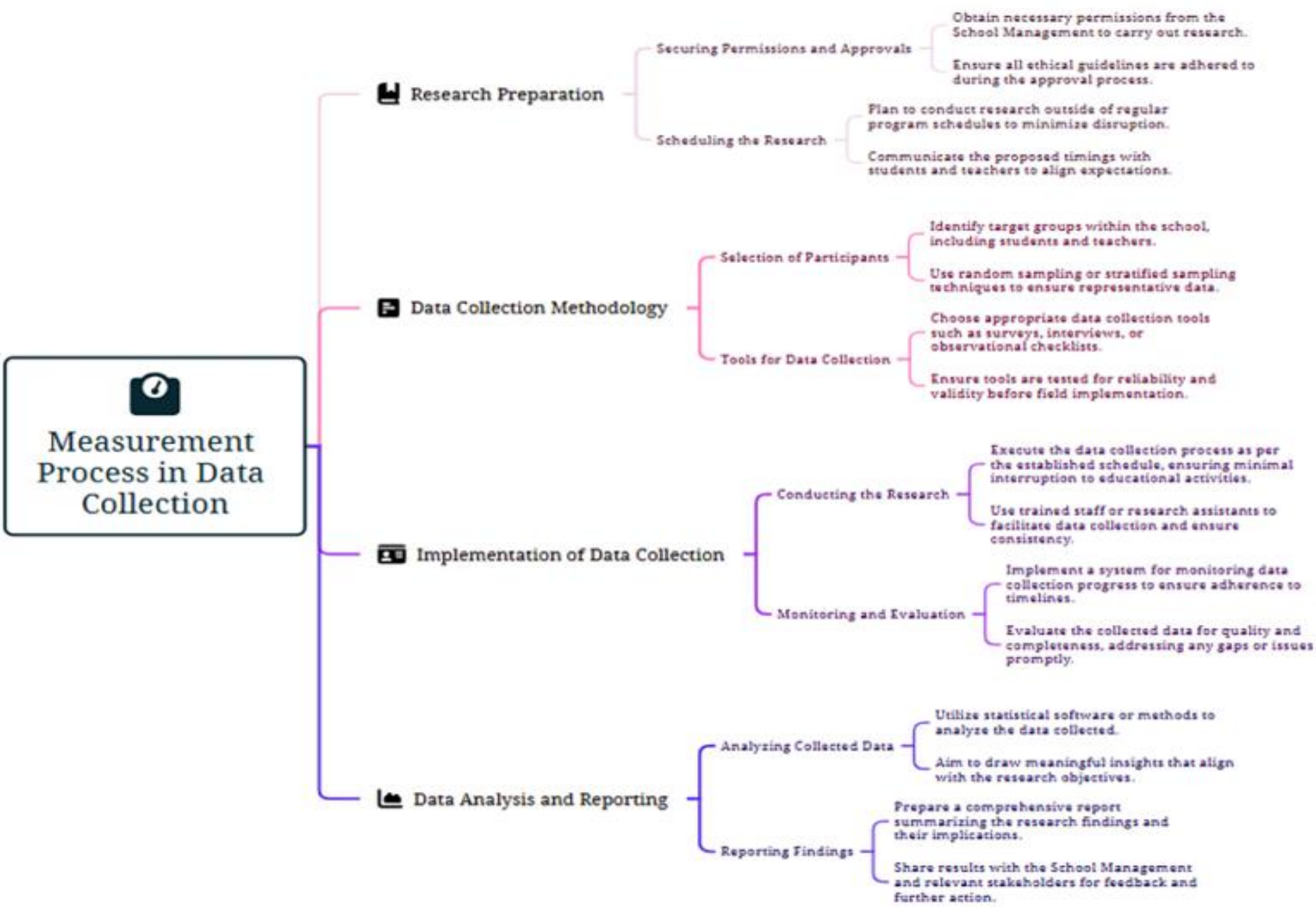

Figure 4. Diagrammatic representation of the process of data collection with student questionnaires (Source: Author's own elaboration)

CONCLUSION: DOCUMENTING THE SIGNIFICANCE OF THE RESEARCH PROTOCOL

The current experimental study tries to propose the use of ERs as a novel pedagogical tool; the main aim will be the detailed analysis of their possible role in enhancing learners' cognitive and visual-spatial abilities, especially concerning complex biological phenomena such as the mitotic process.

The scientific approach of the suggested research initiative is based on the systematic assessment of the pedagogical effectiveness of ERs, with the aim of grasping the extent to which they may serve as a methodological tool for reducing cognitive obstacles and cognitive load associated with the understanding of complex biological mechanisms.

Additionally, the research proposal will seek to provide teachers with empirical evidence that allow them to formulate specific teaching strategies through which they will greatly improve both the cognitive level and learning motivation of the trainees while developing the prerequisite visual and perceptual skills that are essential for an effective approach to biological phenomena. This scientific approach emphasizes the importance of innovative pedagogical methodology in modern educational reality.

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Ethics approval: The present study, as a theoretical investigation, does not fall into the categories of research that require ethics approval.

Availability of data: All data generated or analyzed during this study are available for sharing upon request. Interested parties are encouraged to direct their inquiries to the corresponding author, who will facilitate the provision of the data in a timely and appropriate manner.

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