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EPISTEMIC FUNCTIONS OF MODELS IN THE TEACHING AND LEARNING PROCESS IN CYTOGENETICS: AN ANALYSIS IN THE CONTEXT OF PRE-SERVICE BIOLOGY TEACHERS

Funções epistêmicas de modelos no processo de ensino e aprendizagem em citogenética: uma análise no contexto da formação inicial de professores de biologia

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Resumo

Nesta pesquisa, analisamos como professores de Biologia em formação inicial mobilizam funções epistêmicas de modelos nos processos de ensino e aprendizagem em citogenética. Coletamos dados de interações de um grupo de licenciandos em uma sequência didática sobre divisão celular que envolveu a prática de modelagem. Para análise, transcrevemos situações com maior potencialidade analítica, organizadas em cenas e episódios de ensino. Os resultados indicam que os licenciandos mobilizaram diferentes funções epistêmicas dos modelos em discussão: (i) representar, no sentido de similaridade e no sentido de estar no lugar; (ii) investigar e prever; (iii) comunicar; (iv) dar suporte a argumentos e explicações científicas; (v) simplificar e (vi) disponibilizar uma imagem conceitual. Funções epistêmicas relacionadas à comunicação de ideias e argumentação ampliaram oportunidades para que dúvidas de caráter conceitual e/ou visões distorcidas de alguns conceitos emergissem nas interações. Além disso, o estudo aponta implicações para a formação de professores e o ensino de Biologia, especialmente no que diz respeito ao uso da modelagem não apenas como uma atividade de mera manipulação ou representação de modelos, mas como uma oportunidade para refletir sobre modelos como artefatos epistêmicos ao possibilitar a vivência mais autêntica da prática científica em contextos de ensino.

Palavras-Chave: modelos; funções epistêmicas; ensino de Biologia; citogenética.

Abstract

In this research, we analyze how pre-service Biology teachers mobilize epistemic functions of models in the teaching and learning processes in cytogenetics. We collected data from an interaction in a group of pre-service Biology teachers in a teaching sequence on cell division that involved the practice of modeling. For analysis, we transcribed situations with greater analytical potential, organized in scenes and teaching episodes. The results indicate that pre-service Biology teachers mobilized different epistemic functions of the models under discussion: (i) representation as showing and representation as standing for; (ii) investigate and predictive; (iii) communicate; (iv) to support scientific arguments and explanations; (v) to simplify and (vi) to provide a conceptual image. Epistemic functions related to the communication of ideas and argumentation expanded opportunities for conceptual doubts and/or alternative views of some concepts to emerge in the interactions. In addition, the study points out implications for science education and the teaching of Biology, especially with regard to the use of modeling not only as an activity of mere manipulation or representation as showing, but as an opportunity to reflect on models as epistemic artifacts by enabling a more authentic experience of scientific practice in teaching contexts.

Keywords: models; epistemic functions; Biology teaching; cytogenetics.

INTRODUCTION

In Biology teaching, models have been used as a methodological alternative for teaching topics such as cytology and genetics, since they involve abstract entities, structures and processes that are difficult to visualize (Oliveira & Galembeck, 2016; Puig, Ageitos, & Jiménez-Aleixandre, 2017). In this research, we seek to understand how models play epistemic functions for teaching and learning in cytogenetics[1]. This proposal begins on a broader context: the emphasis on traditional methodologies in the teaching contents relative to cytogenetics (e.g.: chromosomes, mitosis, meiosis) and the difficulties of teachers in innovating in the education of these contents (Barden-Gabbei, 2006; Fernández & Tejada, 2019). In general, the most common instructional resources recorded in the literature are textbooks, lectures, in addition to guidance focused on memorization of various names of structures and processes (Gonzalez-Weil & Harms, 2012; Oliveira & Galembeck, 2016).

Studies on the subject are part of research on the teaching of cell biology, which has advanced based on some predominant trends: the analysis of students' knowledge (por exemplo, Duda & Adpriyadi, 2020; Fuchs, Bonney, & Arsenaut, 2021; Suwono, Saefi, & Susilo, 2019) the difficulties faced by students in learning the contents (Fernández & Tejada, 2019; Gonzalez-Weil & Harms, 2012; Vlaardingerbroek, Taylor, & Bale, 2013) and methodological alternatives for teaching (Felipe, Gallarreta, & Graciela, 2005; Oliveira & Galembeck, 2016; Puig et al., 2017).

Part of these studies refer to genetic knowledge in cytology, which is the object of interest in this article. This research points to some recurrent conceptions among students, such as: (i) the idea that not all living organisms have genes and chromosomes; (ii) that hereditary information is found only in sex cells; (iii) that sex chromosomes are found only in gametes; (iv) that mitosis and meiosis occur in all cell types; (v) the non-distinguishment of somatic and gametic cells; (vi) the lack of link between mitosis and the growth process and (viii) the lack of link between meiosis and the biological inheritance process (Armenta, 2008; Ayuso & Hernández, 2002; Infante-Malachias, Padilha, Weller, & Santos, 2010; Íñiguez Porras & Puigcerver Oliván, 2013; Ruiz-Gonzalez, Banet, & López-Banet, 2017).

Regarding students' difficulties, on its turn, research points to the most common problems such as: i) dimensioning the size of cell structures and scales (Vlaardingerbroek et al., 2013); ii) understanding the internal structure of cells (Gonzalez-Weil & Harms, 2012); iii) recognizing cells as an integrated part of a living being (Vijapurkar, Kawalkar, & Nambiar, 2014); iv) visualizing the cells and their components under a microscope (Fernández & Tejada, 2019).

To overcome these difficulties, research invests in analysis on how to teach these contents in the classroom. There is a consensus in the search for strategies that allow for a more active role of students in the construction of knowledge and the use of resources to handle the microscopic aspects of cytology (Fernández & Tejada, 2019). In this sense, a strategy that has been explored by the research is the use of models and modeling (Oliveira & Galembeck, 2016; Phelan & Szabo, 2019; Puig et al., 2017; Reinke, Kynn, & Parkinson, 2021). Some of this research specifically explores the use of models aimed at building knowledge in cytogenetics.

Clark and Mathis (2000), for example, analyze the use of modeling kits to teach the processes of mitosis and meiosis. The study analyzes a set of activities whose objective was to develop models for the meiosis process and its use in explaining two problems involving errors in cell division. The activities were carried out with students from the introductory biology course on a college education level, who should consult two-dimensional models of meiosis, in order to develop concrete models. The analyzes were built based on the way in which the teacher checks possible conceptual errors in the models and discusses it with the students throughout the preparation process, in addition to interviews carried out after the activities. The

[1] Cytogenetics is a field that studies the structures and functions of cells related to genetics (e.g.: chromosomal structure, mitosis and meiosis processes) (Alberts, Bray, & Johnson, 2011).

results indicated a good acceptance of the material among professors and students, in addition to a greater possibility of making the meiosis process more visible and understandable among the participants.

Barden-Gabbei (2006), on their turn, analyze teacher's actions in the use of models. These actions take place in the context of activities relative to mitosis, meiosis and enzymatic functions, developed with students from introductory biology courses. The analyzes show that the way the teacher used two-dimensional model projections and manipulated concrete models to demonstrate concepts and processes favored student learning in contrast to the format where they only visualize the images in the instructional materials. Similarly to what Clark and Mathis (2000) highlighted, the researcher justifies that the approach used by the teacher favored the understanding of sub-cellular processes that are not visible to the naked eye.

Other research explore genetic knowledge at the molecular level. Their analyzes concern the involvement and learning of students in activities that require the manipulation and/or construction of models for DNA, RNA, protein and gene molecules (Lucas, 2021; Roth, Franz-Josef, Mierdel, & Bogner, 2020)

This research uses a concept of *models as representation*. In other words, models are designed and/or used to represent abstract and difficult to visualize entities (Justi, 2006). This conception is dominant not only in research on cytogenetics, but also in research on the teaching of cytology in general (ver, Barden-Gabbei, 2006; Garimella & Robertson, 2015; Gonzalez-Weil & Harms, 2012; Oliveira & Galembeck, 2016; Vijapurkar et al., 2014; Vlaardingerbroek et al., 2013).

In research such as conducted by Clark and Mathis (2000) and Barden-Gabbei (2006), the term modeling was used to refer to the construction of concrete models. The approaches identified in this work consist in the development of three-dimensional concrete models by students after viewing two-dimensional models in textbooks or concrete models prepared by the teacher beforehand.

In the activities analyzed by Clark and Mathis (2000), the instructional demands show the concept of model as representation. The activities can be understood as a checking practice, as students only prove the validity of a model or theory already learned. When the representative codes and the domains to be represented are already established, the authenticity of model design is limited, because the process of deciding how best to express its ideas is hindered. Furthermore, students may conclude that there is only one way to express the model (Justi, 2006).

In the case of Barden-Gabbei (2006), concrete models and projections acted as teaching models, i.e., artifacts used by teachers in order to favor the explanation and/or visualization of the object to be taught. According to Justi & Gilbert (2002), teaching models are used by the teacher to represent a domain-model, which can be a scientific model or a curricular model, provided that the latter is a simplified version of the first one developed for teaching purposes, varying according to the education level of students. However, the analyzes do not show active participation of students in the proposal, as they acted as consumers of the relationships between domain and the representative code established by the professor. In this type of approach, unlike in the previous one (Clark & Mathis, 2000), the models are manipulated in the classroom only by the professor, for helping students' conceptual understanding.

Another aspect of these studies is the focus on conceptual content. Research on students' knowledge, their difficulties, and the use of models generally discuss conceptual learning in cytogenetics. Proposals capable of going beyond the limits of the conceptual domain in this context and involving other aspects that are central to science education are still scarce. Given the current demands of training students in science and the predominance of traditional methodologies in the teaching of cytogenetics, it is urgent to seek alternatives able to create a balance between the conceptual domain and the epistemic and social domains of scientific knowledge in the classroom (Franco & Munford, 2020, Duschl, 2008; Kelly & Licona, 2018). Teaching science also means generating ways to introduce students to practices in the construction of scientific knowledge beyond the mere transmission and memorization of concepts. Consequently, considering the model conceptions in this research and the conceptual domain of knowledge as the predominant orientation, we believe that it is relevant to increase the depth of discussions on the role of modeling in the teaching of cytogenetics.

In this research, we seek to analyze the models from another perspective, understanding them from their epistemic functions for the teaching and learning processes (Gilbert & Justi, 2016). This conception, although still with a small presence in the teaching of cytogenetics, can bring a series of benefits to the field, considering the relevance of the epistemic formation of students in scientific education in the 21st century (Kelly & Licona, 2018). Using as a reference the concept of the model developed by Gilbert and Justi (2016), which goes beyond its representational function, we can understand models as human artifacts which, somehow materialized, help in the development of various scientific practices and the construction of scientific knowledge. There are few studies, in the context of research on cytogenetics, aligned with model conceptions such as this. The research of Felipe et al. (2005) Puig, Ageitos and Jiménez-Aleixandre (2017) offer relevant findings in this regard.

Felipe et al. (2005) They developed analyzes on creating concrete models for the early embryonic segmentation process of animals with future biology teachers. The study conceived the modeling based on a series of activities in which students (i) used different forms of representation of the developed concepts to formulate descriptions and explanations; (ii) designed their own representations; (iii) critically analyzed the models used and judged their scope and limitations. In performing these analyses, students had to apply the models in different contexts, including cytogenetic content, to explain the meiosis and mitosis processes. Teachers created, tested and evaluated models communicating their ideas in the social plane of the classroom. By doing that, they gained experience working with models, using them as tools to solve problems, and they were also able to reflect on these experiences when discussing the functions of models in scientific research.

In a similar direction, Puig, Ageitos and Jiménez-Aleixandre (2017) analyzed models for gene expression. In this case, the modeling demanded articulations between knowledge at the molecular level (DNA, RNA, gene) and contents at the cellular level (e.g.: chromosome shape, ribosome subunits, nucleus). Students from the 9th grade of Elementary School worked in groups to propose, explain, discuss and decide which would be the best model for the gene expression phenomenon. The analyzes indicated that students showed greater engagement in certain practices related to modeling (e.g.: proposing a model) and difficulties in relation to others (e.g.:, expressing criteria for evaluating the model, communicating model characteristics). Moreover, the authors also identified relationships between modeling and argumentation in students' attempts to develop more sophisticated models.

In this research, there is a compression of the model and modeling that is close to what we propose to explore. We align with these studies seeking to contribute to the area of Science Education, considering the relevance of modeling as a didactic strategy for science teaching and the need to advance in the conception of a model in the teaching of cytogenetics. The use of the concepts proposed by Gilbert and Justi (2016) are important in this dialog, as they attribute an active and reflective role to the student in building these models, with opportunities to explain their ideas, build hypotheses and test them according to the data and by communicating them to their peers. Based on these demands and proposals, the article sought to answer the following research question: *in what way do biology teachers in initial training mobilize epistemic functions of models in the cytogenetics teaching and learning processes?*

To find answers to this question, we analyzed interactions of a group of teachers in initial training. This choice was made based on demands from the field itself, considering the relevance of discussions on methodological alternatives for teaching cytology in initial education (Fernández & Tejada, 2019) and the scarcity of research in this context. Most of the research on the subject is carried out in the context of higher education, and those developed in the context of higher education focus on professionals in the areas of health and biological sciences (Phelan & Szabo, 2019; Reinke, Kynn & Parkinson, 2021; Vlaardingerbroek, Taylor & Bale, 2013) and not on the training of biology teachers (Felipe et al., 2005).

We believe that the reflexive experience of teaching practices unrelated to traditional pedagogy in initial training can contribute to the development of faculty knowledge for education (Diniz-Pereira, 2011), especially in content classically marked by the practices of this pedagogy. For this reason, we analyzed interactions between biological sciences college students in the context of a didactic sequence that aimed to allow reflections on how to teach science, valuing epistemic dimensions of scientific knowledge.

THEORETICAL BACKGROUND

Models in Science Education

In this article we build our views on models from the proposals of Justi and Gilbert (2002) and Gilbert and Justi (2016). Initially, these authors based their modeling proposal on the idea of models as partial representations of reality (ideas, processes, objects, events) built for specific purposes (Justi & Gilbert, 2002). However, criticism of the idea of a model as a representation was essential to update their proposals (Gilbert & Justi, 2016). The first criticism refers to understanding that models are representations of reality, which implies thinking that we have knowledge of reality in order to make us capable of representing it. This would reduce the investigative role of models in science, assuming them only as communication tools. On the contrary, they are widely used as tools involved in building new knowledge. In some areas, such as artificial intelligence, there is no access to what is being represented, as new realities are created through simulations. The second criticism refers to the notion that models are independent agents of theories and data, contrary to the perspective that places them as subordinates. This is justified by the independent character they assume in research processes in science, in the production of knowledge.

Considering the aforementioned criticisms, the authors started to adopt a view of models as thought artifacts or knowledge mediators (Gilbert & Justi, 2016). In this sense, they define models as human artifacts which, materialized in some way, help in the development of various scientific practices and in building scientific knowledge. For the authors, this definition becomes more coherent to the objectives of scientific modeling, since we learn and generate knowledge with models when we imagine and simulate, idealize and make predictions, present arguments and arrive at explanations (Gilbert & Justi, 2016). Considering this definition, we understand models as artifacts that support thought and that assume epistemic functions in scientific investigations. These functions highlight the complexity of using models in science and indicate possibilities for working with modeling in the classroom. The proposal of thinking about models based on their epistemic functions assumes that a model does not represent itself, but requires a social use by someone according to their intentions and purposes in the knowledge-building process. Gilbert and Justi (2016) present the epistemic functions played by models, defined as:

(i) **partial representation**, a function based on which models are understood as representations of objects, events, ideas and processes that have some structural relationship with what is being represented. However, there must be clarity in the understanding of representation, because if representation is being comprehended as similarity, models can be understood as copies of reality or images with different levels of similarity to what is being represented. If representation is being understood as "being in place of" it means that something is replacing what is being represented, in order to allow for reasoning and assist in the preparation of explanations. Considering the semantics view of the model, we understand it as a representation that "is in the place of" the modeled entity, system or process.

(ii) the **investigative function** of the model allows knowledge to be built, thereby used to investigate aspects of the modeled entity or process that are not well known. The investigative function expands the understanding of the model as a representation of reality, provided that, for representing reality one must have knowledge of the entity to be modeled and its form of representation, consequently, there is no investigation when one knows all aspects of the entity to be modeled, whereby knowledge is only being represented and not built as research suggests.

(iii) the **predictive function** of the models is related to the investigative function, since the models are used in behavior simulations relative to the entity to be modeled without have clarity of its real characteristics.

(iv) in the **communicative function**, models are used to communicate an idea, which can be: an argument or a scientific explanation, in the sense of clarifying and informing the community about the scientific knowledge in question.

(v) to support scientific arguments and explanations models are used with the **role of justifying** knowledge and decision-making about the plausibility of a conclusion.

(vi) in the **function of simplifying and idealizing** the models, they are used to favor the resolution of problem-issues and facilitate the understanding of reality when it is complex, focusing on relevant aspects.

(vii) to **provide a conceptual image**, models allow one to visualize with the eyes of the mind objects and processes not directly observable.

Seeking to understand the models in science teaching, from different epistemic functions, it is necessary to bring teaching closer to an epistemological perspective that prioritizes the social justification of knowledge. In science classes, the objective is not to produce new knowledge, but to understand a *corpus* of scientific knowledge consensually agreed upon and established in the scientific community (Kelly & Licona, 2018; Sasseron, 2021). However, this process should not be synonymous with the mere transmission of content, but a continuous process of appropriation of ways of doing and speaking science. In this conception, students are familiarized with the practices of construction of scientific knowledge in order to develop their own forms of expression that characterize their discourse when proposing, justifying, evaluating and legitimizing knowledge in science classes (Kelly, 2008).

Scientific Modeling in Science Education

Modeling in science education has the potential to contribute to a broader view of science because students have opportunities to explore the goals, scope, and limitations of consensual and historical scientific models. Therefore, the epistemic functions of models can appropriate modeling as a scientific practice, while **creating, expressing, testing and evaluating** their own models (Justi & Gilbert, 2002; Justi, 2006):

(i) the **creation** of a model involves the preparation of a first proposal based on the definition and/or understanding of the objectives it must achieve. For the creation of the model it is necessary that the student has some experience with the target to be modeled. These experiences can be previously existing information, such as the students' prior knowledge, or acquired at the time the model was created, for example, through an experiment or data provided by the educator.

(ii) the **expression** consists in the choice of the model representation modes (e.g.: concrete, visual, verbal, mathematical, computational). The selection of the representation depends on the proposal and the nature of the elements to be modeled, which can be static, dynamic, concrete or abstract. Another important aspect is establishing the representation codes, i.e., giving meaning to the material. Students should be aware of the limitations of these different modes of representation, as well as access of the resources available for using each one of them. Due to these limitations and resources, the model originally created will not always be expressed in the same way.

(iii) the **testing** stage occurs when the models are tested against the proposed objectives, i.e., the model must be able to support the required explanations. Tests can be mental, when the subject simulates the situations, and/or empirical, through data collection relative to the modeled entity. At this stage, students should try to convince their peers that their model is the most suitable.

(iv) in the **evaluation**, on its turn, the model is analyzed in terms of its explanatory power, its scope and limitations. This evaluation takes place in an attempt to use the model in situations other than the initial objective. At this stage, students also seek to convince their peers that their model is the most comprehensive.

This conception of modeling is constituted as a practice articulated with other scientific practices, such as argumentation and preparation of scientific explanations (Mendonça & Justi, 2013). These articulations favor building more complex notions about models and modeling in science education.

Argumentation is a central communicative activity in science, as there is a need to justify and adapt models and theories based on evidence, and scientists must be open to criticism in order to be evaluated and legitimized in their epistemic communities (Mendonça & Justi, 2013; Blanco-Anaya, Bustamante, Mendonça, 2019). Argumentation, articulated with the building of models in the classroom, favors the understanding of the scientific status of models in science, and goes against teaching where scientific models are presented as absolute truths, without considering their historicity, their contexts of preparation and their epistemic basis. The preparation of scientific explanations, in turn, is linked to argumentation, since arguments are necessary to justify and persuade the community in question relative to the best explanation (Osborne & Patterson, 2011). Consequently, there is an intrinsic relationship between modeling, as a process of elaboration and critique of models, argumentation and preparation of scientific explanations. In modeling, the designed models guide and support the argument's justifications, and the latter helps assessing the adequacy of the models, converging to produce a consensual explanation, designed based on a model and evaluated based on evidence (Mendonça & Justi, 2013; Blanco-Anaya, Bustamante, Mendonça, 2019). Based on these proposals, modeling is understood as an authentic scientific practice in the classroom, and not just a manual activity for the production of representations (Osborne, 2014).

METHODOLOGY

Collection and construction of data

We present the analysis of an activity on chromatin and chromosome that made up a teaching sequence on mitosis. The development of the sequence occurred in the subject called “Supervised Internship in Biological Sciences Teaching” I (10th Term of the college course - Biological Sciences Degree - at University XXXX), with a total of 18 undergraduate students enrolled. In this subject, science teaching methodologies are discussed, teachers undergoing initial training plan activities and experience teaching experiences that aim to articulate theory and practice in the classroom. We believe that it would be of great importance to develop the teaching sequence in this discipline, as it seemed an interesting proposal to work on the experience of scientific practices, providing undergraduate students with the development of epistemic practices, thus contributing to a more authentic learning of Science.

The proposal of the teaching sequence (Cláudio & Mendonça, 2021) sought to expand the work possibilities of teachers in initial training with cytogenetic content based on a group of six activities (Table 1) guided by the steps of modeling according to Justi & Gilbert (2002) and Justi (2006) and by the learning objectives proposed by Duschl (2008):

(i) conceptual: seeking to explore the processes that involve cell division, covering all the way from the initial concepts about DNA to genetic conditions caused by errors in cell division, such as Down syndrome;
(ii) epistemic: seeking to make students question why we know what we know in order to reflect on the knowledge under construction;
(iii) social: seeking to insert students into a set of social norms related to the representation and communication of knowledge under construction.

Table 1: Synthesis of the teaching sequence developed with the investigated group (for more details, see Cláudio & Mendonça, 2021).

Activity	Objective	Brief description
1	Having experiences with the target: DNA extraction laboratory practice	The students performed a plant DNA extraction, discussed the meanings of the procedures necessary to carry out that practice, and started a discussion about the structure of DNA.
2	The role of evidence and argumentation in model-building	Students held discussions based on ideas from texts about how science built a model for the DNA molecule. The proposal was to understand the role of evidence-based argumentation in the construction of scientific models.
3	Construction and use of models: chromatin and chromosomes	Students built models for chromatin, single, homologous and duplicate chromosomes. From the proposal, students had to communicate and discuss their models with their peers.
4	Building and using models: cell cycle	The students developed a model for the cell cycle, discussing phases G0, G1, G2 and synthesis, whereby the mitosis process could be discussed in more depth in the following activity.
5	Construction and testing of the mitosis model	Students built models of mitosis based on scientific evidence from optical fluorescence micrography of the process. There were discussions about the possibilities and limits of using this evidence.
6	Mitosis Model Evaluation	Students used the developed model to assess claims about the content of mitosis. Then, the group sought to use the model to explain phenomena that occur in the human body, such as cell mosaicism and Down syndrome.

The researcher (2st author of this article) was responsible for conducting the teaching sequence, in agreement with the professor of the discipline. Therefore, this intervention is close to participatory research, where the researcher interacts with those involved in the investigated situations (Cohen, Manion, & Morrison, 2011).

The research was guided by a qualitative approach to educational research, provided we did not focus on the product of learning, but on its process (Cohen et al., 2011). The classes in which the didactic sequence was developed were recorded on video and audio, since by doing that, subsequent access to the discussions in the classroom was made possible, allowing for the analysis of the interjections and reactions of the undergraduate students and the researcher.

Analysis Processes

We have developed the analysis processes at different levels of work with the data. At first, the videos of the classes were watched for a mapping of practices that interested us: analyzing and interpreting data, building evidence, preparing scientific explanations. Based on this identification, at a later stage, the classes were transcribed. The transcription was not made in full, but only of interactions with greater analytical potential. Based on the transcript, we build teaching episodes to develop analysis of interactions.

Based on the definition of Carvalho (2006), teaching episodes are “moments extracted from a class, where a situation that we want to investigate is evident” (p. 33). To select the episodes, we identified excerpts from classes in which it was possible to identify discussions that helped us to build answers to our research problem. Also, according to Carvalho, the same episode may not be continuous, organized into scenes by the researcher. Therefore, the interactions that refer to the situation under analysis may not occur in the same period of time, with interruptions between different moments of the same class or in different classes. Consequently, it is up to the researcher to articulate the scenes that constitute an episode, building meaning to the data (Carvalho, 2006). From these proposals, we selected scenes in which the mobilization of epistemic functions of the models where more visible in the participants' interjections. We transcribed these scenes, which formed two episodes selected for analysis in this article. These episodes occurred within the interactions of class on the didactic sequence detailed in table 1.

The analysis of the episodes was developed based on interactions in which the participants' interjections were identified in turns according to the transcript made[2]. These tables were produced with three columns: the first with the number of speaking turns, the second with the transcription of the speeches and the third with the images of the models and/or gestures related to the models and used by the participants. We used fictional names to identify research participants[3]. To analyze the interactions, we started based on discussions about epistemic functions performed by Gilbert and Justi's (2016) models, and prepared the following analysis categories:

1. Representing: When pre-service teachers provided two interpretations regarding representation: (i) as a copy of reality and (ii) to be "in the place of".
2. Investigating and predicting: When (i) the undergraduate students used models to understand some aspect of the entity to be modeled that was not clarified and (ii) at times when the investigative function was linked to the predictive function, since students made predictions about the conformations of chromosomes and the consequences of these conformations in the cell-division process.
3. Communicating: When pre-service teachers used the model to communicate an idea, argue and provide explanations.
4. Support scientific arguments and explanations: When the model was used by undergraduate students to (i) justify in the structuring of an argument, (ii) when proposing a scientific explanation or to (iii) evaluate the explanations presented, for example, if the subject disagrees with them, they use the model to justify said disagreement.
5. Simplifying and conceiving: When the models were used by pre-service teachers to simplify a complex and/or abstract process to solve problem issues and focus on aspects considered more relevant in the proposition.
6. Provide a conceptual idea: When the model was used by pre-service teachers to conceptualize processes that are not easily observable, but that there are inferences on them.

RESULTS AND DISCUSSION

Episode 1: Homologous chromosomes?

The first episode under analysis refers to the moment in class 3 when the preparation and communication of models of the structure of chromatin, simple, duplicated and homologous[4] chromosomes occurred among the participants. Faced with the demand for communication of the models, undergraduate student Bruna presented the model proposed by her group (Table 1), without, however, preparing explanations on the proposal. She understood that the model spoke for itself, approaching the sense of

[2] In addition to the content of the interjections, we also identified pauses, represented by (...); and our comments or explanations about the lines, marked by two parentheses (()) (Carvalho, 2006)

[3] We adopted ethical principles of research in education, seeking to preserve the identity of the participants, valuing their well-being, privacy and safety. To participate in the research, the undergraduate students signed the Informed Consent Waiver (FICF), where they were informed about the study objectives, the risks and benefits thereof. The research was approved by the research ethics committee of the relevant institution.

[4] When the cell is performing its functions in the organism, the DNA is in its less condensed form, configuring the chromatic form, which is a complex of DNA and proteins. These proteins include histones that are positively loaded, making it easier for DNA, which is negative, to fold. Each complex of DNA plus histones is called a nucleosome and the set of nucleosomes is the chromatin. When the cell is in the mitotic phase of the cell cycle, the DNA has a high degree of condensation, in this conformation it is characterized as a chromosome. Chromosomes are simple when there is only one DNA molecule. For cell division to occur, each DNA molecule is duplicated, characterizing itself as a duplicated chromosome. Homologous chromosomes refer to pairs of chromosomes with information from the father and mother respectively.

representation as “being in the place of”. Bruna's group mobilized the epistemic function of **simplifying**, as it chose to represent only some chromatin structures, in addition to the function of **providing a conceptual image**, since the group made inferences about what chromatin is and transposed it to the model.

Table 1: Episode 1 - Scene 1

1.	Bruna: This one is our chromatin ((Shows the model to everyone)).	 **Figure 1**: Model for chromatin

Source: prepared by the author

In order to better explore the model, the researcher started to question the groups about the choice of material. Daiana replied:

Table 2: Episode 1 - Scene 2

2.	Daiana: that's because we are.... ((gestures showing that the material is already rolled up)) it's because it's as if it were condensed...	 **Figure 2**: Gestures to explain chromatin

Source: prepared by the author

In scene 2, the licentiate Daiana mobilized the **epistemic function of “being in the place of”** by saying “it's as if it were”. She indicated that she used the model to represent the modeled entity. Her talk also mobilized the model to **support scientific arguments and explanations**, as he established a relationship between the coiled coil and the fact that DNA is condensed. This epistemic function of the model is mobilized from the researcher's questioning, in order to favor a reflection on knowledge in the development of scientific practice. To help her explanation, Daiana also used the gestural mode (in addition to the concrete mode), allowing the interpretation that she was communicating an idea associated with representation, mobilizing the **communicative** function of the model. Her hands represented the chromosome, and she was able to express the idea that associated the condensed chromosome with the spiral-shape. Based on the gestural mode combined with the concrete, it is possible to perceive a mistaken interpretation by Daiana, as she suggests that, in the form of chromatin, the DNA is more condensed, and this occurs in the form of a chromosome. Then, Bruna continued presenting the models:

Table 3: Episode 1 - Scene 3

3.	Bruna: here the homologous chromosomes ((shows the model to everyone))... here we just...	 **Figure 3**: Model of a duplicated chromosome
4.	Researcher: Is this the homologous chromosome?	
5.	Bruna: no... this is the homologous chromosome... ((student takes another chromosome model)) homologous chromosome would be these ((she shows the two	

	homologous chromosome models correctly and classmate Eduardo nods in agreement))	 **Figure 4**: model of homologous chromosome pair

Source: prepared by the author

Bruna, in turn 3, presented the concrete models and showed a duplicated chromosome as being homologous. The models were used for **simplicity**, as they chose some structures to represent, such as the alleles and the centromere, as evidenced by the figures. In turn 4, the researcher questioned Bruna if that model (figure 3) was really of homologous chromosomes. The undergraduate student acted as if it had been just a mix-up in handling the models, because as we can see in Figure 4, she showed the two pairs of homologous chromosomes correctly. At that moment, the student Eduardo agreed with the presented model. In scene 5, below, Bruna continued presenting the models:

Table 5: Episode 1 - Scene 5

6.	Bruna: here we only set the parameters for... as if they were the sister chromatids in this case, right? ((Looks at her partner, Cristina, who nods in agreement))... and here it would be the two... the male and the female... in this case it would be a woman... this one is our simple chromosome... ((When Bruna said it would be a woman, Eduardo made an expression revealing he found it odd))	 **Figure 5**: model of homologous chromosomes  **Figure 6**: Single Chromosome Model

Source: prepared by the author

In turn 6, Bruna showed that she marked the two chromatids with play dough of the same color to show that they are sister chromatids. Subsequently, she revealed understanding that the duplicated chromosomes have two sister chromatids, despite not explaining whether the marking corresponds to alleles for a trait. Again, we see that the model was used for **simplification purposes**. In this same line, it is possible to identify that the student mobilized the **representation function as "being in the place of"**, using the expression "as if it were". Then, Bruna showed the two homologous chromosomes, stating that this set would form the genotype of a woman, as they are two Xs, and presented the single chromosome correctly, as shown in Figure 6.

In scene 5, Bruna also used the model to **communicate** an idea that generated disagreement among her classmates. When Bruna said that the chromosomes she had made were from a woman because they were XX, she associated the shape of the X chromosome with the didactic representation of the sex chromosomes being X and Y. This led to disagreement and the need for Bruna's to justify her speech, as evidenced by Eduardo's reaction:

Table 6: Episode 1 - Scene 6

7.	Eduardo: yeah.... Why would it be a woman?
8.	Bruna: it's because in my head, if it were the male chromosome, it would be smaller here, wouldn't it?
9.	Eduardo: ((He remained silent for a moment and with an expression revealing he was not understanding)). No... but they are homologous, that's the father and the mother... to be a girl or a man the rest of the process should have already occurred...

10.	Bruna: oh, I understand...
11.	Researcher: especially because there is something else... did you make the sex chromosomes? ((At this moment everyone shake their heads indicating NO))
12.	Bruna: no
13.	Cristina: otherwise we would have made an X and a Y. ((students confirm the statement by nodding their heads))

Source: prepared by the author

In scene 6, the model was being used as a **communication** tool and **to support scientific arguments and explanations.** Students were seeking clarification of a scientific concept as they discussed the homology of chromosomes. Bruna prepared a justification, using the model, despite the fact it was not coherent from a conceptual standpoint. The chromosome represented in the shape of an X created a conceptual confusion, because, in addition to the undergraduate students not understanding why the chromosomes were represented in this format, they confused them with the sex chromosomes, because they were represented as X and Y. So the researcher started the next episode by questioning Bruna about the reason for having proposed the X-shaped chromosome model.

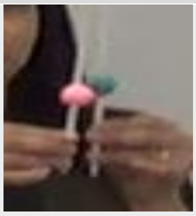
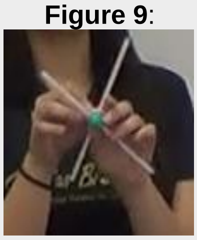
In summary, by engaging in modeling in episode 1, undergraduate students mobilized the epistemic functions of: **representing how to "be in the place of"; communicating**; **simplify; providing a conceptual image; supporting scientific arguments and explanations.** In these interactions, we highlight the role of the communicative function of the model, which allowed identification of incoherent interpretations, from a conceptual point of view, favoring the engagement of the students in the practice of argumentation, as shown in scenes 5 and 6. Therefore, the mobilization of epistemic functions of the model gave visibility to knowledge of the conceptual domain under discussion. Knowledge about chromatin, chromosome types and the notation used to represent them emerged when the students had to communicate ideas about the model.

Episode 2: Chromosomes in X?

Episode 2 refers to the moment in class 3 when the participants resumed the discussion about the X chromosome and went deeper into the issue. The researcher struck a conversation about the representation of this chromosome in the shape of an X, asking Bruna's group the reason for the representation:

Table 7: Episode 2 - Scene 1

1.	Researcher: Another question... can I borrow your model? ((Asks Bruna's model)) explain to me why you did it ((the chromosome)) in the X shape?	 **Figure 7**: model for duplicated chromosomes
2.	Daiana: to better represent the two... ((gestures showing that they are joined))... the two simple ones joined.	 **Figure 8**: Gesture to show placement of duplicated chromosomes.
3.	Researcher: are they joined in X?	
4.	Daiana: not always.	
5.	Eduardo: no.	
6.	Researcher: are they ever?	
7.	Daiana: yes	
8.	Researcher: What makes you think they will be in an X shape at	

	some point?	
9.	Cristina: because the book shows them like that ((Students nod and laugh))	
10.	Eduardo: in the static model it is like this.	
11.	Daiana: most representations are usually...	
12.	Researcher: why is that? Is there an error there in the didactic representations? ((Moment of silence))... Because in the centromere... what will connect a simple chromosome - lend me the simple one you made... ((asks Bruna)) What's going to link this chromosome... oh you made two... can I borrow them? ((points to another group))... here it would have to be the same color right? so they can bond...	
13.	Renata: all you have to do is change...	
14.	Researcher: No... it's okay... let's imagine they're the same color... what makes them bond?	
15.	Eduardo: the centromere...	
16.	Researcher: it's the centromere... what's in the centromere that I didn't talk about earlier... but what links the simple chromosome to the other is an enzyme... a protein called cohesin... the cohesin that makes the chromatids themselves link to form a chromosome... because if cohesin that links here ((handles the model)) why do we always make this representation? ((handles the model of the chromosomes and puts them in X))	 **Figure 9**:  **Figure 10**: X-shaped duplicated chromosome model.
17.	Daiana: It's because, as we were saying... it's usually represented like this... that has even become...	
18.	Eduardo: a convention...	
19.	Daiana: yeah...	
20.	Researcher: Do you think this is a correct convention?	
21.	Eduardo: I don't know now...	

Source: prepared by the author

At the beginning of the scene, Daiana gestured to show that the chromosome's sister chromatids are joined. When gesturing, she did not cross her arms, showing that the gesture was consistent with the scientific concept. However, when asked by the researcher, in turn 3, if the chromatids are joined in X, according to the model developed, she said that "*not always*" and Eduardo, from another group, said "*no*" - which shows a contradiction with the knowledge in question. In this discussion, students used the model to support scientific **arguments and explanations** and for **communicating**.

By gesturing, Daiana **communicated** her ideas in order to be able to **prepare an explanation** for the conformation of the chromosome and her gesture indicated that she was representing the chromosome, and, therefore, she also used the **function of representing how "to be in the place of"**. After turn 3, where the researcher questioned whether the chromosomes are in X, the participants started to mobilize the **investigative and predictive** function of the models. They discussed the conformation of the chromosome, and to that end, they made predictions to simulate how chromosomes behave.

The researcher questioned Daiana when she said "*not always*" regarding the X-shaped bonding of sister chromatids. The researcher demanded justification for the student's statements (shifts 8 and 12). In turn 9, Cristina said that everyone represented the chromosome in the X format, because it appears like this in the textbook and her colleagues agreed. Eduardo stated that the static model is like that and Daiana concluded by saying that most representations are usually like that. Therefore, to Cristina, Daiana and other classmates, the model would be like a **copy of reality**.

Eduardo's statement showed that he understood the model a little differently from other students, since, when referring to the model as static, he considered that there is no way to handle the model, but if it were possible, students would realize that they are in parallel and not in X. Eduardo's speech provided evidence of a vision of **representation as "being in the place of"**, in a way that the model would be replacing what was being represented, in order to allowing reasoning.

In turn 12, the researcher questioned the reason for this representation in X-shape. The students were silent, indicating that even when they considered the conformation might not be in X, they had not prepared an explanation for it. The researcher, at that time, used the model with an **investigative and predictive** function and as a **representation of "being in the place of"**, as she handled the model seeking to understand more about the chromosome and making predictions. After the researcher demonstrated that the chromatids are parallel and linked at the centromere, she questioned why this representation is unusual and is commonly represented in X. The undergraduate students stated that because they always see the chromosomes represented in X, they never questioned or sought to understand the reason behind said representation. Daiana even stated that this representation is a convention. Again, we highlight the students' view of representation in the sense of being a copy of **reality**. Following the interactions (scene 2), the researcher continued to question the undergraduate students and asked for an explanation about the conformation of the chromosome:

Table 8: Episode 2 - Scene 2

22.	Researcher: ... I think it's important for us to discuss these things with the students: oh, so the chromosome is in X, but why? Who said so? Oh, why is it in the book like this... as Cristina said? But the chromosomes are not in X... the cohesins bind and they stick here and what happens... we see more or less the structure there, don't we? Folded like that, right? ((Researcher handles the model)) ((Students confirm saying "yes" and "right")) Researcher: then it gives you the impression that this part is this... ((handles the model)) So it looks like it's in X... but it's not actually in X... they're stuck together by cohesin... because if they were in X wouldn't it be good for mitosis? ((Students don't say anything)) because there has to be an explanation...	 **Figure 11:** model for showing chromosome position.
23.	André: Because half of the information is on one side and the other part on the other.	
24.	Eduardo: *Crossing over* wouldn't be possible.	
25.	Researcher: at the time of cell division... how is this chromatid here from the father or the mother going to divide when it is in an X... will they detach? are they going to break? how is it going to be done?	
26.	((Students nod agreeing that it could be X-shaped))	
27.	Researcher: so why is it important for us to problematize... when we start to think... what is the conformation? We see that it doesn't make much sense and that what we are teaching in the classroom is often wrong.	
28.	Cristina: and we're still learning today... ((Students agree))	
29.	Cristina: Oh my God... I learned everything wrong so... OMG...	
30.	Eduardo: you are graduating and everything you learned was wrong...	

Source: prepared by the author

In turn 23, André presented a coherent explanation when he said that if the chromosomes were in X, it would not be possible for separation to happen in mitosis, since the chromatids would separate. Models are being used to **support scientific arguments and explanations**. Taking advantage of the explanation given by André, the researcher used one of the models to show that the genetic material could be damaged if the chromatids were to break abruptly. In turn 25, the researcher used the model with the **investigation**

and prediction function, as she supposed what the process would be like if the chromosome were in X-shape. In turns 28 to 30, the undergraduate students were uncomfortable because they had learned something they passed to consider to be wrong, showing a content that could have been more explored/problematized in teaching and which ultimately became an imposed truth for them.

In short, in this episode, we had problematization of the structure of the X chromosome, whereby the model was mobilized with epistemic functions: **investigative** and **predictive, providing support to scientific arguments** and **scientific explanations, providing a conceptual idea** and **representation in the sense of being in place** or **as similarity.** At the beginning of the episode, the speeches of the undergraduate students are more declarative and without problematization or argumentation. The researcher's questions for the model to be used as an epistemic tool in the construction of knowledge proved to be important throughout the interaction. Through the developments generated by their questions, the model went beyond the function of representation in the sense of copying reality. Furthermore, similarly to what was observed in episode 1, the mobilized epistemic functions gave visibility to knowledge of the conceptual domain under discussion.

CONCLUSIONS

In this research, we present interactional data analysis with Biology teachers in initial training in order to answer the following research question: *how do these Biology teachers mobilize epistemic functions of models in the cytogenetic teaching and learning processes*? Pre-service teachers (undergraduate students) used the models under discussion with the following epistemic functions:

(i) representing: this function was used in two ways: in the sense of similarity, whereby undergraduate students reproduced the textbook model or as they already knew it, thus making a copy of reality, just building the model in three-dimensional mode; and in the sense of “being in the place of”, when they handled the model to provide explanations and establish conclusions, favoring knowledge-building.

(ii) investigating and predicting: initially the models were not used as investigative and predictive tools, but based on the researcher's questions about the structure of the X chromosome, these functions were mobilized, as both the undergraduate students and the researcher used the model to predict chromosome behavior in mitosis.

(iii) communicating: the model was used as a communicative tool, as the pre-service teachers discussed each representation code used and prepared explanations about the model for the whole class, as they had to convince that the model was valid. Furthermore, they expressed different points of view about the models, had to argue about the productions and reach a consensus on the models.

(iv) for supporting scientific arguments and explanations: undergraduate students built explanations within an argumentative context, in order to obtain a more adequate explanation about the modeled entity.

(v) simplifying: when producing the models, the undergraduate students chose to represent DNA structures that they considered coherent with the model's objective, selecting which aspects were more relevant and represented them, simplifying a more complex phenomenon.

(vi) providing a conceptual image: students made inferences about chromosomes and chromatin, although these are structures that are not easily observable.

More broadly, these results offer contributions to research in the field of Science Education and, more specifically, to the demands of teaching Biology. In a broader sense, the results point to possibilities of articulation between different domains of scientific knowledge: conceptual, epistemic and social (Duschl, 2008). The area has sought to advance the understanding this type of articulation, insofar as the proposals for more harmonious curricula lack classroom data capable of highlighting their potential and challenges (Franco & Munford, 2020, Sasseron, 2021). Our data indicate that the mobilization of epistemic functions of the models increased opportunities for conceptual doubts and/or distorted views of some concepts to emerge in the interactions. That is, conceptual knowledge about cell and cell division was better discussed because participants were engaged in practices from the epistemic and social domains of science (e.g. investigating, predicting, communicating, explaining). In this way, the results contribute to the area, which has sought to advance in the understanding of this type of articulation, insofar as the proposals for more harmonious curricula lack classroom data capable of highlighting their potential and challenges (Franco & Munford, 2020; Sasseron, 2021).

Furthermore, our results indicate that epistemic functions related to the social domain of science, such as communicating ideas and engaging in argumentation from questioning, played a relevant role. Unlike what has been recurrent in the literature on cytogenetic models, the mobilization of these epistemic functions positioned modeling not as a mere manipulation activity (Puig et al., 2017), but as a more authentic experience of scientific practice (Osborne, 2014). Practices such as communicating ideas and engaging in argumentation based on questioning positioned modeling not as an activity of mere manipulation, as indicated by literature (Puig et al., 2017), but as a more authentic scientific practice experience (Osborne, 2014). The critical analysis of the models, seeking to legitimize knowledge, indicated alternative forms of teaching other than those based on the authority of the teacher or the instruction (Sandoval, 2014) material and commonly observed in the covered contents (Fernández & Tejada, 2019; Oliveira & Galembeck, 2016).

Regarding the teaching of Biology, our data reinforces the results of research on learning difficulties in cytogenetics. Teaching episode 1, for example, pointed out the difficulties in distinguishing between chromatin and chromosome types, the conception that sex chromosomes are found only in gametes, and confusion in the distinction between chromosome types and the notation used to represent them. In teaching episode 2, on its turn, it was possible to observe contradictory conceptions around the shape of the chromosome, especially when considering different phases of mitosis. These difficulties became evident when students had to communicate ideas about the model and were asked about their views. These notions are also common among higher Education students in cytogenetic content, as evidenced by a series of studies (Armenta, 2008; Ayuso & Hernández, 2002; Infante-Malachias et al., 2010; Íñiguez Porras & Puigcerver Oliván, 2013; Ruiz-Gonzalez et al., 2017). Our data also make it possible to understand that the use of models as epistemic artifacts contributed to these difficulties being worked out punctually during the modeling stages, since they became evident when the pre-service Biology teachers had to communicate ideas about the model and were questioned regarding to your visions. This approach facilitates the teaching and learning process, as the teacher is able to identify difficulties and discuss them along the way.

One of the gaps identified in the training process of undergraduate students was the distinction between teaching models and the phenomena represented by said models. This challenge was evidenced in the interactions we analyzed and is something that is also reflected in Higher Education (Fernández & Tejada, 2019). The X chromosome, for example, when represented didactically in the form of an X, does not, in principle, constitute a conceptual error. However, it is important for the teacher to discuss with students the distinctions between the shape of chromosomes, especially when viewed under a microscope, as well as the name of the X chromosome. However, it is important for the teacher to discuss with students the distinctions between the shapes of chromosomes, especially when they are observed under a microscope, and the naming of the X chromosome. There is no correspondence between the X notation of the chromosome and the X shape of the chromosomes in metaphase. One way to address these aspects is to provide students with a reflection on models as *epistemic tools* (Kelly & Cunningahm, 2019), so that they have opportunities to reflect on the knowledge that is being produced and evaluated (Puig et al., 2017), not using models only as a representation function in the sense of similarity, as usually happens in the classroom (Oliveira & Galembeck, 2016; Vijapurkar et al., 2014).

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REFERENCES

Alberts, B., Bray, D., & Johnson, A. (2011). *Fundamentos da Biologia Celular* São Paulo, SP: Artmed

Armenta, M. C. (2008). Algunas ideias del alumnado de secundaria sobre conceptos básico de genética. *Enseñanza de las ciencias, 26*(2), 227-244. Recuperado de https://raco.cat/index.php/Ensenanza/article/view/118096

Ayuso, G., & Hernández, E. B. (2002). Alternativas a la enseñanza de la genética en educación secundaria. *Enseñanza de las ciencias, 20*(1), 133-157. https://10.5565/rev/ensciencias.3983

Barden-Gabbei, L. M. (2006). Demonstrating Biological Principles Efficiently & Effectively: The Overhead Is More than Just a Lighted Chalkboard. *The American Biology Teacher, 68*(8), 357-361. https://doi.org/10.2307/4452012

Blanco-Anaya, P., Bustamante, J. D., & Mendonça, P. C. C. (2019). Las destrezas argumentativas en la evolución de modelos en una actividad de geología. . *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias, 16*, 3105. https://doi.org/10.25267/Rev_Eureka_ensen_divulg_cienc.2019.v16.i3.3105

Carvalho, A. M. P. (2006). *Uma metodologia de pesquisa para estudar os processos de ensino e aprendizagem em salas de aula* Ijuí, RS: Unijuí.

Clark, D. C., & Mathis, P. M. (2000). Modeling Mitosis & Meiosis: A Problem-Solving Activity. *The American Biology Teacher, 62*(3), 204-206. https://10.2307/4450874

Cláudio, D. S. O., & Mendonça, P. C. C. (2021). Construindo práticas científicas no processo de ensino e aprendizagem do ciclo celular. In L. G. F. (Org.). (Ed.), *Ciência em contexto: propostas para construir espaços-tempos de ciência na escola* (Vol. 269-297). São Paulo, SP: Na Raiz.

Cohen, C., Manion, L., & Morrison, K. (2011). *Research Methods in Education* (7th ed.). London and New York: Routledge.

Diniz-Pereira, J. E. (2011). A prática como componente curricular na formação de professores *Revista do centro de educação UFSM, 36*(2), 203-218. https://doi.org/10.5902/198464443184

Duda, H. J., & Adpriyadi. (2020). Student's Misconceptions in Concept of Biology Cel. . *Anatolian Journal of Education, 5*(1), 47-52. https://doi.org/10.29333/aje.2020.515a

Duschl, R. A. (2008). Science education in three-part harmony: balancing conceptual, epistemic and social learning goals. . *Review of Research in Education, 32*(1), 268-291. https://doi.org/10.3102/0091732X07309371

Felipe, A. E., Gallarreta, S. C., & Graciela, M. (2005). La modelización en la enseñanza de la biología del desarollo. *Revista Electrónica de Enseñanza de las Ciencias, 4*(5), 1-32. https://doi.org/10.14483/23448350.12972

Fernández, M. M. F., & Tejada, M. P. J. (2019). Difficulties learning about the cell. Expectations vs. reality. *Journal of Biological Education, 53*(3), 333-347. https://doi.org/10.1080/00219266.2018.1469542

Franco, L. G., & Munford, D. (2020). O Ensino de Ciências por Investigação em Construção: Possibilidades de Articulações entre os Domínios Conceitual, Epistêmico e Social do Conhecimento Científico em Sala de Aula. *Revista Brasileira de Pesquisa em Educação em Ciências, 20*. https://doi.org/10.28976/1984-2686rbpec2020u687719

Fuchs, T. T., Bonney, K. M., & Arsenaut, M. (2021). Leveraging Student Misconceptions to Improve Teaching of Biochemistry & Cell Biology. *The American Biology Teacher, 83*(1), 5-11. https://doi.org/10.1525/abt.2021.83.1.5

Garimella, U. I., & Robertson, B. M. (2015). Modeling the Shapes of Cells *Mathematics Teaching in the Middle School, 21*(3), 180-188. https://doi.org/10.5951/mathteacmiddscho.21.3.0180

Gilbert, J. K., & Justi, R. (2016). *Modelling-based Teaching in Science Education*: Springer International Publishing

Gonzalez-Weil, C., & Harms, U. (2012). Del árbol al cloroplasto: concepciones alternativas de estudiantes de 9º y 10º grado sobre los conceptos «ser vivo» y “célula”. *Enseñanza de las ciencias: revista de investigación y experiencias didácticas [en línea], 30*(3), 31-52. Recuperado de https://raco.cat/index.php/Ensenanza/article/view/285682

Infante-Malachias, M. E., Padilha, I. Q. D. M., Weller, M., & Santos, S. (2010). Comprehension of basic genetic concepts by brazilian undergraduate students *Revista Electrónica de Enseñanza de las Ciencias, 9*(3), 657-668. Recuperado de http://reec.webs.uvigo.es/volumenes/volumen9/ART9_Vol9_N3.pdf

Íñiguez Porras, F. J., & Puigcerver, O. M. (2013). Una propuesta didáctiva para la enseñanza de la genética en la Educación Secundaria. *Revista Electrónica de Enseñanza de las Ciencias, 9*(3), 657-668. Recuperado de https://dialnet.unirioja.es/servlet/articulo?codigo=4541890

Justi, R. (2006). La Ensenãnza de Ciencias Baseada en La Elaboración de Modelos. *Enseñanza de las ciencias, 24*(2), 173-194. Recuperado de https://raco.cat/index.php/Ensenanza/article/view/75824

Justi, R., & Gilbert, J. K. (2002). Modelling, teachers' views on the nature of modelling, implications for the education of modellers. *International Journal of Science Education, 24*(4), 369-387. doi:https://doi.org/10.1080/09500690110110142

Kelly, G. (2008). Inquiry, actitivity and epistemic practice. In R. Duschl & R. Grandy (Eds.), *Teaching scientific inquiry: recommendations for research and implementation* (pp. 288-291). Rottherdan: Holand: Tapei Sense Publishers

Kelly, G., & Cunningahm, C. M. (2019). Epistemic tools in engineering design for K-12 education. . *Science Education, 103*, 1080-1111. https://doi.org/10.1002/sce.21513

Kelly, G., & Licona, P. (2018). Epistemic practices and science education. In M. Matthews (Ed.), *History, Philosophy and Science Teaching: New perspectives* Springer International Publishing.

Lucas, K. L. (2021). The use of 3-D modeling and priting to teach the central dogma of molecular biology. *Science Activities: Classroom Projects and Curriculum Ideas, 58*(2), 70-76. https://doi.org/10.1080/00368121.2021.1918048

Mendonça, P. C. C., & Justi, R. (2013). The relationships between modelling and argumentation from the perspective of the model of modelling diagram. *International Journal of Science Education, 35*(14), 2407-2434. https://doi.org/10.1080/09500693.2013.811615

Oliveira, M. L., & Galembeck, E. (2016). Mobile Applications in Cell Biology Present New Approaches for Cell Modelling. *Journal of Biological Education, 50*(3), 1-14. https://10.1080/00219266.2015.1085428

Osborne, J. (2014). Teaching Scientific Practices: Meeting the Challenge of Change. *Journal of Science Teacher Education, 25*(2), 177-196. https://doi.org/10.1007/s10972-014-9384-1

Osborne, J., & Patterson, A. (2011). Scientific Argument and Explanation: A Necessary Distinction? *Science Education, 95*(2), 627-638. https://doi.org/10.1002/sce.20438

Phelan, S., & Szabo, E. (2019). Undergraduate lab series using the K562 human leukemia cell line: Model for cell growth, death, and differentiation in an advanced cell biology course. *Biochemistry and Molecular Biology Education, 47*(2), 1-9. https://10.1002/bmb.21222

Puig, B., Ageitos, N., & Jiménez-Aleixandre, M. P. (2017). Learning Gene Expression Through Modelling and Argumentation: A Case Study Exploring the Connections Between the Worlds of Knowledge. *Science & Education, 24*(4), 1193–1222. https://10.1007/s11191-017-9943-x

Reinke, N. B., Kynn, M., & Parkinson, A. L. (2021). Immersive 3D Experience of Osmosis Improves Learning Outcomes of First-Year Cell Biology Students. *CBE Life Sci Educ., 20*(1). https://10.1187/cbe.19-11-0254

Roth, T., Franz-Josef, S., Mierdel, J., & Bogner, F. X. (2020). Sef-evaluative Scientific Modeling in an Outreach Gene Tecnhology Laboratory. *Journal of Science Education and Technology, 29*, 725-739. https://doi.org/10.1007/s10956-020-09848-2

Ruiz-Gonzalez, C., Banet, E., & López-Banet, L. (2017). Conocimientos de los estudiantes de secundaria sobre herencia biologica: implicaciones para sua enseñanza. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias, 14*(1), 550-569. http://dx.doi.org/10.25267/Rev_Eureka_ensen_divulg_cienc.2017.v14.i3.04

Sandoval, W. (2014). Science Education's Need for a Theory Epsitemological development. *Science Education, 98*(3), 383-387. http://10.1002/sce.21107

Sasseron, L. H. (2021). Práticas constituintes de investigação planejada por estudantes em aula de ciências: Análise de uma situação. *Ensaio: Pesquisa em Educação em Ciências, 23*, 1-16. https://doi.org/10.1590/1983-21172021230101

Suwono, H., Saefi, M., & Susilo, H. (2019). *Challenge based learning to improve scientific literacy of undergraduate biology students*. In Atas 6th International Conference for Science Educators and Teachers, Bangkok, Thailand.

Vijapurkar, J., Kawalkar, A., & Nambiar, P. (2014). What do Cells Really Look Like? An Inquiry into Students' Difficulties in Visualising a 3-D Biological Cell and Lessons for Pedagogy. *Research in Science Education, 44*(2), 307-333. https://10.1007/s11165-013-9379-5

Vlaardingerbroek, B., Taylor, N., & Bale, C. (2013). The problem of scale in the interpretation of pictorial representations of cell structure. *Journal of Biological Education, 48*(3), 154-162. https://10.1080/00219266.2013.849284