THEMATIC SECTION: FAUNA, FLORA, OTHER LIVING BEINGS AND ENVIRONMENTS IN SCIENCE AND BIOLOGY EDUCATION

Drosophila melanogaster: a meeting point for History, Philosophy, Sociology, and Biology teaching

Julio Alejandro Castro Moreno[I]
Irma Catherine Bernal Castro[I]

[I]Universidad Pedagógica Nacional (UPN), Bogotá – Colombia

ABSTRACT – *Drosophila melanogaster*: a meeting point for History, Philosophy, Sociology, and Biology teaching. *Drosophila melanogaster* has been the subject of several studies in history, philosophy, sociology, and teaching of biology, evidencing the relevant role it has played as a model organism for experimental practices in genetics and other areas. However, these works are not usually closely intertwined. Therefore, this article intends to contribute to the establishment of links between these areas, understanding the fly as a point of convergence. From this perspective, it proposes to broaden the view on the nature of science, which is an important reference for teachers to make biology teaching more complex.
Keywords: **Nature of Science. Biology Education. Model Organism.**

RESUMEN – *Drosophila melanogaster*: un punto de encuentro de la Historia, la Filosofía, la Sociología y la didáctica de la Biología. *Drosophila melanogaster* ha suscitado diversos estudios en la historia, la filosofía, la sociología y la didáctica de la biología, evidenciando el papel relevante que ha desempeñado como organismo modelo de prácticas experimentales de la genética y otras áreas. Sin embargo, dichos trabajos no suelen entrelazarse estrechamente. Por ende, este artículo pretende aportar en la constitución de vínculos entre esos ámbitos, entendiendo a esta mosca como un punto de convergencia. Desde esta perspectiva, se propone ampliar la mirada sobre la naturaleza de la ciencia, la cual es un referente importante para que los profesores puedan complejizar las prácticas de enseñanza de la biología.
Palabras-clave: **Naturaleza de la Ciencia. Enseñanza de la Biología. Organismo Modelo.**

http://dx.doi.org/10.1590/2175-6236124150vs02

Introduction

Drosophila melanogaster[1], also known as "fruit fly" or "vinegar fly" perhaps is the most important model organism in biology, into research in genetics and embryology specially, but nowadays for the role developed in studies in molecular biology and biomedicine. Without doubt also has been a relevant organism in biology education in different educational levels. Moreover, *Drosophila* has been the subject of reflection and analysis in history, philosophy, and sociology of biology. Nonetheless, is common that those different approaches there are not related.

In this sense, our aim is precisely to establish some links between history, philosophy, sociology, and biology didactics, on purpose that we have learned -and that we can teach- with this minute but significative fly. In other words, the *Drosophila* can constitute a *meeting point* between those alluded areas and theoretical constructions that emerge from this convergence could configurate an important reference framework to biology teachers, understanding, since other perspective, the nature of science that they pretend to teach. In this sense, in this article we report our proposal about how to contribute to the integration of the aforementioned fields, based on the research carried out in the specialized literature on the subject.

There is a question that could be common ground in those ambits: How does a fly works? The Molecular Biologist François Jacob (1998) formulate it when he commented an anecdote when he was a primary student. A classmate of his brought flies to school[2] and, to understand how these animals worked, he took specimens and then began to "disassemble", that is, to remove their parts: wings, legs, etc., until they died. "Once this was done, he would have liked to "reset the system" and put each piece back in its place. But there was no chance of getting it" (Jacob, 1998, p. 47).

Childs and students in general, can understand a lot of things about organisms without it being necessary to "disassemble" them. To learn about nature of science also brought ethical issues: we cannot and should not treat other living beings as we please. But, in addition, is important to approach in the best way possible the curiosity to understand how these organisms are, behave, are built and work. This requires raising animals like *Drosophila,* observe their lifecycle, identify their behaviour, and rid them of pathogens or competition with them for food and space. The pioneers in implement and develop these procedures were scientists like Thomas Hunt Morgan and their collaborators, such as Kohler reports (1993; 1994; 1999).

Kohler also reports on a crucial situation for the topic at hand: In United States *Drosophila* it was part of school practices before coming to inhabit the scientific laboratories properly. To this we can add also that the fly later occupied a prominent place in other types of laboratories, such as those used in the training of biologists (Matta, 2010) and biology teachers (Castro, 2013). In other words what it is about is a series of itineraries that *Drosophila* has followed, since its natural habitat to the human environment, within those that stand out scientific and educational scenarios. The convergence of these trajectories highlights the meeting point that we referred previously.

It is important to highlight that this proposal has a theoretical nature and aims to be a reference for biology teachers to make complex the nature of science, which is essential to enrich teaching practices. Then, we have structured this article in four principal sections, taking as resource the constitutive elements (axis) of nature of science proposed by Adúriz-Bravo (2005)[3].

A *historical axis*, where we will show how the *Drosophila* became part of "life in the laboratory"; a *philosophic axis*, where we will show up the epistemological, ontological, and ethical status of *D. melanogaster*, approached as a "model organism"; a *sociological axis*, where we will approach the social relations and the academical exchanges between different researchers of the fly; and, a *didactical axis*, where we will emphasize the educative value of this insect in biology teaching. In the last part, we will present final considerations, highlighting how *Drosophila* is situated at a prolific crossroad that allows us to enlarge the view of the nature of science.

Drosophila melanogaster **Itinerary: from natural history to laboratory ecology**

Although this article emphasizes *Drosophila* as a model organism – the central theme of the third section –, we coincided with Morioto & Pietras (2020) when they stand that the fact of considering the fly in this way, related to experimental work context has left aside another aspect of this animal: their lives in natural habitats where it develops crucial ecological roles. That is to say that its natural history has been overlooked. In this sense, it should be noted that in order to understand this organism in all its magnitude and show how it has become an inhabitant of scientific, university, and school laboratories, it is necessary to account for its previous existence, before it intertwined its life with the human cultures.

According to Keller (2007), *D. melanogaster* is native form equatorial Africa, from where it migrated dispersing throughout almost the entire planet, just like *Homo sapiens*. Indeed, Keller stands that *Drosophila* have become a commensal of our species and have travelled with us to diverse corners of the world. Furthermore, we could affirm that this fly has perfectly adapted to human life, becoming a member of our societies and cultures: it is a cosmopolitan species dependent on anthropogenic food sources.

Into the scientific spheres, *D. melanogaster* was initially described and nominated by the German Johann Wilhem Meigen in 1830[4], meanwhile in the United States was baptized as *Drosophila ampelophila* by

Joseph Albert Lintner in 1875, the year in which probably it came to this country (Keller, 2007). A short time after, approximately in 1901, it made its incursion into scientific laboratories, and early 1910 gave significant proof of its capabilities as an experimental organism in genetics (Kohler, 1993).

Kohler´s statements (1993; 1994; 1999) are essential to develop our argument, so in that section and the following ones we will base ourselves mainly on them. In the first instance, the author's account of how the *Drosophila* went from being a wild animal to being an inhabitant of human societies, acquiring a "semi-domestic" nature, to finally become a standard organism of laboratory. In this way, Kohler shows how the fly due to its versatility it has managed to adapt to different environments; some of natural character and others of cultural nature. Within the latter, we are interested in highlighting the scientific and educational environments.

Scientific[5] are principally research laboratories in genetics, embryology, and other fields of biology. Kohler asserts that the artificial space of the laboratory was where the *Drosophila* managed to colonize a new ecology, in which there are other rules of selection and survival, thus establishing a symbiotic relationship with the "drosophilists" [6] or "the fly group" led by Morgan. Since this point view, Kohler affirms that, in the same way as the fly was transformed by the practices of the researchers, they also changed their practices due to the qualities of *Drosophila*.

Despite the imaginary that the *Drosophila* was initially part of genetic studies, the fact is that before it was used in research on physiology, ethology, and evolution. In addition, Morgan was not the first working experimentally with this fly; the pioneer was William E. Castle, in Harvard University, whose example other researchers surely followed (Kohler, 1993). One of them was precisely Morgan himself, who transformed the fly in an excellent "instrument" to understand the hereditary transmission of some traits. It was Morgan and his colleagues who "standardized" the *Drosophila* and succeeded in establishing the first chromosome maps, founding in this way the mendelian genetics. All the above was possible because of the fly's traits: It has a short lifecycle, it produces a numerous progeny, it is possible to maintain in a small space and with scarce food, in variable environmental conditions, but not extreme, and it tends to mutate in a short time. Finally, it has ideal qualities for laboratory work.

However, according with Kohler (1993), the entrance of *Drosophila* into the laboratory ecology was marked by inconvenient: it was considered an undesirable animal, especially because is associated with dirty places and, furthermore, it had to compete with widely used experimental organisms such as mice. For this reason, the fly entered the laboratory by the backdoor. In the same way, as was mentioned above, this animal did not engage in experimental work on genetics but had previously been part of studies about the evolution. Particularly, Morgan wanted to put on proof his idea of mutation – understood like abrupt change – with populations of *Drosophila* and demonstrate then that the modification in the environment produces transformations in the organisms, allowing in this way evolutionary changes. It was based on this type of work that Morgan foresaw that the fly could shed light on the elusive problem of hereditary transmission.

A relevant discovery, but not the first, was the identification of a male with white eyes in 1910 by Morgan when the colour red is the rule[7]. Several new mutants would then be identified, which is why Kohler (1993; 1994; 1999) calls the *Drosophila* a "reactor-breeder": A system capable of produce mutations, which in turn lead to more experiments in which new mutations are revealed, and so on.

In summary, between the fly and the "drosophilists" new ecological-cultural interactions were established and strengthened. Kohler (1993, p. 308-309)[8] expresses it in these terms:

> This symbiotic relationship transformed *Drosophila* physically into a new domesticated creature, one that did not exist in nature and that could only have been created in the peculiar ecology of a genetics laboratory. And so, too, did it transform the fly people into a new variety of experimental biologist, with distinctive repertoires of work and a distinctive culture of production.

This relationship led, among other aspects, to the *Drosophila* becoming a model organism[9], a matter that we will develop immediately.

Drosophila melanogaster like Model Organism: The ontological, epistemological, and ethical status of experimental animals

According with Daston y Galison (2007) all sciences must select and build *working objects*, which contrast with the abundant and variated *natural objects*. For them, the central issue is that no sciences can carry out it work without such active and standardized objects. But, how do these objects go from being in a "natural state" to becoming proper scientific objects? This question can be resolved based on the categories proposed by Daston (2000): prominence, emergency, productivity, and rootedness.

Prominence is a word used to describe the multiple ways in which some phenomena or entities calls the scientific attention, and, for this reason, they are transformed into scientific objects. The *emergency* allows to postulate a radical form of novelty: it is about the irruption of scientific objects without everyday prehistory, for example, some mathematical objects, i.e., that emergency is a genuine "bring to existence". *Productivity* refers to that scientific objects never are inert, they get their ontological status due to production of results, implications, surprises, links, manipulations, explanations, and applications. About, rootedness, it is important to note that the objects have a scientific character to the extent that they are the target of an epistemic activity. This becomes manifest, for example, when experimental systems embed scientific objects within the wide field of a scientific, material, and practical culture.

Until now we have referred to scientific objects in a general way, but in what sense can animals, like the *Drosophila*, be equated to scientific objects? Especially since the end of the 19th century, some animals came to take part in biological experiments, which took place in a specific space: the laboratory. Different organisms were confined to the laboratory and developed a series of anatomical, physiological, and behavioural traits, among others. that have allowed humans to manipulate these properties and use them to extrapolate them to other types of studies. In short, these animals gave rise to "model organisms" (Weber, 2008).

According to Ankeny y Leonelli (2011, p. 313), model organisms[10] are:

> […] non-human species that are extensively studied in order to understand a range of biological phenomena, with the hope that data and theories generated through use of the model will be applicable to other organisms, particularly those that are in some way more complex than the original model. They also have a variety of experimental advantages; notably they are easy to breed and maintain in large numbers under laboratory conditions.

The authors also explain two attributes of these organisms that make them, precisely, "models". In first place, we have a "representational scope": it is possible extrapolate the results obtained with a specific experimental organism to a broad spectrum of organism which usually includes the human being. Secondly, we face it "representational target": which are the phenomena that can be investigated through these organisms. Thereby

> […]: while the representational target describes the conceptual reasons why researchers are studying a given organism, the representational scope defines the extent to which researchers see their findings as applicable across organisms (Ankeny; Leonelli, 2011, p. 315).

A key issue is that model organisms are configurates such it due to standardization process carried out into laboratory ecology. This point can be illustrated perfectly with the *Drosophila*, insect that fully complies with everything that is required for experimental work:

> […] model organisms have particular experimental characteristics that are closely related to their power as genetic tools: they typically have small physical and genomic sizes, short generation times, short life cycles, high fertility rates, and often high mutation rates or high susceptibility to simple techniques for genetic modification (Ankeny; Leonelli, 2011, p. 316).

As we said above, were Morgan and colleagues whose constituted the *D. melanogaster* in the ideal standard organism to genetics. However, what does it mean to understand an organism as a "standard"? This may mean that it has been "manufactured" by human practices – in this case, laboratory-, with the intention that it fulfils certain functions that allow to elucidate certain problems, like the hereditary transmission of characters. Likewise, the idea of a standard carries a broader context than a particular laboratory, such as that of Columbia University, where Morgan and his team worked with *Drosophila*. We will take up this topic in the next section.

To Kohler (1994, p. 14), a standard means "[…] the things that everyone uses". Here "everyone" denotes the people who are part of similar research projects, and that they implement similar practices to solve the problems that are significant to them. The standard term alludes not only to the fly itself but also to some tools that were elaborated thanks to it and are used by "everyone" like genetic maps. As is well known, the *Drosophila* allowed to establish relations between the behaviour of chromosomes and the hereditary transmission of certain traits. Also, thanks to this animal, was possible to understand the linkage between genes and the interbreeding process[11].

It is a commonplace of historical and philosophical studies of biology to refer to model organisms in general, and the fruit fly in particular, as instruments: flies are analogous to instruments in many ways, "Ecologically, for example, they survive only in the artificial environment of a laboratory" (Kohler, 1999, p. 244).

Is since this point of view that Castro (2019) had called the attention about the ontological and epistemological status of a model organism, like *Drosophila*, accounts of this animal simply as an instrument, an artifact, or a tool used to perform experiments. In such terms, a fly would be the equivalent to, putting just in case, a thermometer. Or, according with Ankeny and Leonelli (2011, p. 317), "[…] the model organism is understood as a test tube for achieving a full understanding of all biological processes". In a wider way, such organisms also are conceived as technology: "Experimental creatures are a special kind of technology in that they are altered environmentally or physically to do things that humans value but that they might not have done in nature" (Kohler, 1994, p. 6). Weber (2005), for his part, proposes that did not take this kind of affirmation literally, due to biologists did not build the model organisms, but they modify them. In addition, he says, these organisms, unlike the instruments, help to identify phenomena that occur within them, not outside of them.

But, regardless of the language used, we consider that model organisms should not be understood in the way indicated, because the ontological status – what kind of entities they are – and epistemological – what can we know *about* them and *with* them – must be complemented with its *ethical status*: An experimental animal like *Drosophila* does not have to be treated as an instrument or a tool, since it is a living and sentient being, whose existence deserves respect. Despite living in the laboratory, that life must be dignified (Castro, 2019).

Anyway, it is important to have in mind that experimental work with *Drosophila* was the foundation for the construction of genetic maps, which, together with strains of flies, became a "bargaining currency" among groups of researchers. This leads us to explore other questions of a sociocultural nature raised by the scientific practices in which *D. melanogaster* has been implicated. In this way, in the next section we approach a topic that accounts for the sociological axis of our proposal: how the habits of intellectual interchange between different research groups were key to the constitution of the fruit fly as model organism, principally in genetics. This allows us to approach to social dynamics of scientific communities and understand the knowledge scaffolding as the result of a process of interaction between subjects, which deploys a series of practices that are entrenched in long-standing experimental traditions.

Drosophila melanogaster, the 'Drosophilists' and the moral economy: the social relationship *within* the Morgan´s laboratory and *between* the laboratories of scientific research on the fly

The mutant strains of *Drosophila*, as well as the genetic maps, came from standardized organisms and instruments, which allowed sent to diverse laboratories in the world, where were used in the same forma as "drosophilists" did. This gives, as a result, its universalization: different researchers, separated by space, but linked for working on similar problems share a cumulous of theoretical-practical knowledge, as the one that is implied with the experimentation with the fruit fly. Of course, this experimental activity originated in a restrained context, in Morgan´s laboratory at Columbia University, but gradually it embraced a wider action ratio, in part due to the interchange strategies with diverse research groups situated across the planet.

Marxist historian E. P. Thompson proposed the idea of "moral economy", which have been resignified by Kolher (1994; 1999) to account for how social relations were established and strengthened *within* the team led by Morgan and *between* this group and other similar groups. Following Kolher´s statements, the moral economy of the "fruit fly group" was characterized by 1) the access to the interchange tools; 2) the equity in the assignation of credit, which means public recognition; and 3) the authority in the configuration of research agendas and to decide what worth's to be inquired. Kolher highlights, in the same way, that in this group, a set of relationships was established such as, to name a few, division of labour and reciprocity. Not all the members did the same, but they did it following common goals.

On the relationship with other groups, Kolher (1999) says that these relations consist in "interchange webs", which are exemplified with the production of manuscripts, books and papers, in particular, that they helped to spread the results of their work; but *Drosophila* mutant strains were also exchanged, and experimental techniques and protocols were socialized. It is from this perspective that Kohler (1999, p. 245) affirms that:

> Standard fly and map, moral economy, and exchange network arose together – produced each other, one could say: the material, social, and moral [and literary] aspects of a remarkable machine for producing genetic knowledge.

Kohler (1999, p 246) also asserts that experimental life, regarding the *Drosophila*, should not be seen as a solely biological or exclusively cultural issue, but must be understood as an inextricable mixture between nature and culture "[…] and nature and culture must also blend seamlessly in histories and sociologies of experimental life".

And, as we say before, this way of life experimental, established and developed by the "drosophilists", emphasized collaboration, which implied that the group received visitors to work within it so that they could learn in practice the ways of approaching the problems that the *Drosophila* helped to elucidate. Some of those visitors were graduate students and even university and school professors. Since this perspective, Kohler (1999, p. 250) states that the fly group did not see his visitors as disciples who should follow his directions to the letter. However, that group yes "[...] had many devoted alumni, but it was not a 'school'".

In our view, this group could be considered "a school" in at least two meanings of the term: as a current of thought and action, and as a community in which one teaches and learns. We´re interested in highlighting that, with Morgan and his colleagues, teachers were trained who, upon returning to their institutions, put into practice what they had learned with the "drosophilists": "[Morgan] turned to teachers of biology in small colleges, inviting them to perform some part of the *Drosophila* work in return for a Ph.D. degree" (Kohler, 1999, p. 254). In addition, we consider that the habit of exchanging knowledge and material elements can be a base so that the *Drosophila* has also become a resource and a teaching strategy.

This is evident from the fact that, in the context of the training of biology teachers and biologists, it is common to learn about genetics, and other areas, through experimental work with flies. In other words, it is possible that the *Drosophila* mutants have arrived at different university laboratories thanks to the exchange processes described, where they adapted to a different life and habitat: experimental life in the educational laboratory environment. According to Sofer & Tompkin (1994), the community of research with *Drosophila* is broad, which evidences why many schools and universities have places where flies are cultivated and maintained, allowing to novel students become familiar with these insects, learning how to care for them. Thus, we can affirm that *D. melanogaster* is also a model organism for biology teaching (Pasini; Bertolottoa; Fasano, 2010; Harbottle; Strangward; Alnuamaani; Lawes; Patel; Prokop; 2016).

Drosophila melanogaster as Model Organism in Biology Teaching

Utilization of organisms in biology teaching obeys in part, according to Mayer (1980), the aim and scope of this science. Initially, the study of Biology was in the fields of systematics and morphology aiming at the exploration of preserved specimens, dissected or prepared, in this way the use of these organisms in the classroom did not emphasize experimentation, but in the observation with confirmatory approach, converting the laboratory into a scenario where students worked with non-living organisms mainly for dissection practices, with the purpose of observing, labeling and memorizing. However, it is recognized that there is little to be gained from this type of practice, compared to the diagrams available in textbooks.

Nowadays, the role of the organisms in education have changed, what has affected the content and conceptual load of biology courses at school, giving more importance to the structure and identification of diverse organisms, including into the curriculum topic such as molecular biology, genetics, ecology and behaviour, among others, reducing significantly the practice and the trade of animals to dissections, and enlarging the development of laboratories with preserved or alive animals (Mayer, 1980), within which the most estimated is the *Drosophila*.

In the educational field, the reasons to select *Drosophila* as a model organism are related to the principal arguments of its utilization in scientific research; is highlighted in the school the ease of cultivating the insect, its short life cycle, its maintenance, and cultivation requires little space, it is a low-cost animal, it presents a great variety of mutant strains, etc. Added to this, currently, genetic textbooks provide sufficient information related to the use of this fly as a model organism (Snustad; Simmons, 2012).

Beyond the enormous interest that *Drosophila* has awakened in scientific work, the university and the school as educational scenarios have recognized the potential of this organism in biology teaching, particularly genetics teaching. Despite the impact that this area has on daily life, students state that its content represents great difficulty (Bahar; Johnstone; Hansell, 1999; Fauzi; Ramadani, 2017). For example, have been identified problems with the understanding of the concept of “dominancy” (Abraham; Perez; Price, 2014), as well as, in the relationship between genetic and phenotypic variation, and its implications in the understanding of evolutionary and biomedical processes (Page; Crook, 2022).

In all cases, the work with *Drosophila* in the school requires using of living organisms and the management of standardized methodologies. Generally, scholar practices began with the presentation of protocols that includes the elaboration of growth medium for the maintenance of the individuals, as well as indicating the type of observation and recording that must be carried out[12].

In this sense, and according to Pasini, Bertolottoa, and Fasano (2010), *Drosophila* is the eucaryotic organism more utilized in biology class, due to the properties that we already signaled, which allows us to develop little scholarly projects. Authors in the same way affirm that this fly has been a model organism of biology for almost a century and has allowed research on genetic issues and other nature. But how can we understand the *Drosophila* as a model organism for both biology and its teaching? It seems that, according to what is stated in this article, *D. melanogaster* first did part of the experimental work in genetics laboratories to later "colonize" educational environments. This is not entirely true.

Kohler (1999) affirms that exists a rooted story, but wrong, about that was Morgan who to work on genetic issues, trapped wild exemplars of *Drosophila* and cultivated them in his laboratory, due to this fly fits perfectly in Mendelian perspective and it will help to give light on the problem of hereditary transmission. According to Kohler (1999, p. 245), this story has passed generation after generation of biology students turning into a myth: "It is a tidy, rational story, pedagogically useful for socializing students; but it is not a true account of the mess of real research. The fly's advantages were real enough, but they were not why Morgan initially took up the fly [as an experimental organism]".

In effect, *Drosophila* already was an inhabitant of other laboratories, different from Columbia University, before Morgan put his attention to it, however, we cannot forget that were the "drosophilists" who made the fly a model organism. Previously, *D. melanogaster* was a resident of some scholarly laboratories. Before turning into the "genetics vedette" (Jacob, 1998), our minute fly was employed by biology teachers to make demonstrations about tropisms, sexual dimorphisms, and, in this sense, its principal advantage was to be an excellent organism to develop scholarly activities:

> In fact, there is evidence that *Drosophila* was first brought into laboratories primarily because it was ideally suited to student projects: it was abundant in the fall in gardens and orchards and active through the winter, when live material was needed, and cheap and easily replaced when inexperienced students killed off cultures. Plants and rodents, in contrast, were seasonal or expensive to maintain, subject to blights and epidemics, and not forgiving of student mistakes. *Drosophila* was uselul for student work, but for that very reason its status as an instrument of research was decidedly low. That is, until it was serendipitously taken up in genetic experiments (Kohler, 1999, p. 245-246).
>
> *Drosophila*, in short, was nicely adapted to the collegiate environment and the cycle of academic seasons (Kohler, 1993, p. 296).

Drosophila had an early success in educational scenarios, but, at the same time, this situation made that high-level researchers didn´t see it with good eyes. So, is not risked affirming that, although the fly entered the scientific laboratories through the back door, coming from the educational institutions, it remained linked to the new form of experimental life, thus becoming a model organism. And in this way, it returned modified and empowered into the scholar scenarios properly. Then, is not crazy to affirm that *Drosophila* also is a model organism to biology didactics, although this is not limited to genetics teaching:

> *Drosophila* offers a way for teachers to help students make connections between populations, the organism, the cell, the chromosome, the gene, and the DNA [...]. We feel that the major value of doing the fly lab lies not in the genetics, per se, but rather in the opportunity to expose the student to a living animal which they rear and manipulate to generate real data. Often, a student will initially find a vial seething with larvae to be disgusting, but later that student will be found to be staring, fascinated, through the stereoscope/microscope at just such a vial (Pasini; Bertolottoa; Fasano, 2010, p. 1166)[13].

In short, biology teaching supported in practices with *Drosophila* isn´t restrained to genetic issues; this fly also has been utilized as an educational resource in the teaching of other processes and phenomena present in the curriculum, such as, to cite a few: lifecycles (Demczuk; Nunes; Silva, 2007), Development of scientific skills (Intra; Pasini, 2016), populational growth (Beals; Krall, 2010), Behavioural patterns – geotaxis, chemotaxis, or phototaxis – (College Board, 2012) and evolution, especially the concepts of natural selection and genetic drift (Plunkett; Yampolsky, 2010).

But, regardless of the above, it is important to have in mind that once the fly became a model organism for genetics, it had important repercussions in the school context. In the first part of the XX century, authors like Demerec and Kaufman (1940) recognized the significative contributions of the "vinegar fly" in the development of genetics – which assumes that one of the great scientific achievements of the first decades of this century – and he remarks on its contributions to the teaching of this science. Based on the above, students should have access to the flies themselves and learn the scientific procedures which already have become tradition, principally in Morgan´s laboratory. In the decade of 1950, was promoted the employment of *Drosophila* for teaching at the secondary level of some principles of genetics; it is suggested that teaching is more effective if class discussions are accompanied by laboratory work (Paloumpis, 1953).

Quoting Demerec and Kaufman (1940), Sofer and Tompkin (1994) affirms that, over the years, the *Drosophila* has established itself as a very useful organism in secondary schools for teaching Mendelian genetics, as well as other biology topics[14]. However, they said that fly, not being a vertebrate, implies that "[...] is not subject to the rules and regulations that have been set up for working with such organisms" (Sofer; Tompkin, 1994, p. 418), which could imply that the *Drosophila* does not have an ethical status and that its existence does not deserve respect from us.

Unfortunately, this situation does not seem to be an isolated case, due to diverse didactical proposals promoted a cruel treatment to *Drosophila*. For example, in the project *droso4schools*[15] described by Harbottle et al. (2016, p. 19), despite the fact that it is claimed that inspiring and memorable teaching activities are carried out through experimentation with living organisms and attending to various topics of the school curriculum, at the same time, work protocols that involve dissecting and staining *Drosophila* larvae are socialized, and it is indicated how "[…] shaking epileptic flies into seizure or paralysing flies by warming them to body temperature". Also affirms that:

> These exciting and didactically valuable lessons are possible using *Drosophila* as a teaching tool as it is one of a few established laboratory organisms that is easy to breed and use in schools, cheap and ethically unproblematic (Harbottle et al., 2016, p. 19).

Certainly, these practices should not develop in the school, because students could become skilled in experimental procedures, but become insensitive to other forms of life (Grilli, 2018; Ortiz, 2018). Life in the laboratory does not have to be undignified.

To face these reprehensible treatments, grounded in unjustified ethical positions, it is necessary that the school be committed to respecting the existence of other living beings. One way to undertake this enterprise is to work with living organisms without harming them, but instead allowing students to understand how the animals used in laboratory practices are and behave. As we said in the introduction, we can learn how a fly work without the need to "disassemble it". Since this perspective, in literature, many teaching strategies have been reported that take *Drosophila* as a didactical resource and at the same time foster respect for this insect.

One of this works is the proposal developed by Demczuk, Nunes y Silva (2007), who inquired about the spontaneous conceptions of elementary school students about the life cycle and metamorphosis, using *Drosophila* cultures, which had to be observed and described by the students, recording their observations and descriptions daily in a notebook. This kind of practices would help promote respectful treatment of other agencies.

It seems that there is a tendency to teach issues about lifecycles using *Drosophila*, and the paper of Kurvink (2004) is not an exception. In effect, this author affirms that students like to work with living organisms, like *D. melanogaster*. Direct observation of this animal allows to the students appreciate the appearance of the different stages of metamorphosis, as well as identify pathogenic organisms such as some fungi.

Nissani (1996), since another approach, recounts the experience carried out with four groups of students, each of whom was supplied with two vials containing between ten and twenty *Drosophila*. The containers had to be arranged horizontally, and undisturbed, on the desk and then note how the flies behaved. Specifically, the author was interested in the students being able to identify some "dancing flies" and observe other behaviours that seemed striking to them. For the subject at hand, the article by Nissani (1996) has added value, since it is the only one that we have found where the Nature of Science is explicitly alluded to, emphasizing that students understand, through work with *Drosophila*, how scientific inquiry is carried out.

Nevertheless, Garcia-Carmona, Vazquez and, Manassero (2011), affirm that the nature of science should not be confused with scientific procedures, since practicing them and learning the nature of science are not the same thing. Without a doubt, this distinction is important, but it does not have to lead us to question the relevance of practical knowledge, both in learning science and in reflections on the nature of science. We often learn laboratory techniques, how to manipulate scientific instruments, or how to breed model organisms, but we almost never question ourselves about how that knowledge has come to be what it is and why it is scientific knowledge itself. The nature of science is not eminently theoretical and conceptual; science does not restrict itself to its theories. In the last instance, scientific knowledge must also be assumed from a practical and value perspective.

On the other hand, it is important to highlight that the works consulted on the educational value of the *Drosophila* do not explicitly allude to the nature of science, in relation to the historical, philosophical and sociological aspects, a topic that, for its part, is to which Aduriz-Bravo (2005) puts his attention, maintaining that the history, philosophy and sociology of sciences are "meta-sciences", that is, disciplines that take science as such as the object of study: "*In the didactics of sciences we talk about 'nature of science ' to refer to a set of meta-scientific ideas with value for the teaching of natural sciences*" (Aduriz-Bravo, 2005, p. 12, italics in the original).

In the same way of argumentation, Matthews (2017) raises an important distinction: it is one thing to teach aspects *of* science – for example, what a chromosome is, or a gene – and another thing is to teach aspects *about* science – what is science, how is it elaborated and how is it transformed over time[16]. Precisely, this last scenario is that of the nature of science, which contributes to broaden the perspectives from which to approach scientific issues in the classroom:

> Like all teachers, science teachers must think 'seriously and deeply' about the subject matter they teach; is another way of saying that all teachers should think about [the sociology,] the history and philosophy of their subject. Teachers require an educational compass, but there are many, and they all point in different directions. Philosophy is necessary to make an educational compass that points to the educational north [...] (Matthews, 2017, p. 523).

Our “educational north” is to recognize the *Drosophila* as an organism that foster the teaching of Nature of Science. However, it is necessary to underline that this meta-knowledge must be addressed in teacher training programs[17], establishing interdisciplinary reflections around the internal and external functioning of science, the construction and development of scientific knowledge, the methods used to validate and disseminate knowledge, the values and emotions involved in scientific activities, etc. As is well presented by Garcia-Carmona, Vasquez and Manassero (2011, p. 408) a scarce comprehension of nature of science in education “It can only be remedied with adequate training on these issues, both in initial training and in permanent [teacher] training”.

Consequently, the previously mentioned axes, sociological, philosophical, and historical, should not be addressed in a disaggregated manner, but rather comprehensively. It is from this point of view that in this article we have proposed that *D. melanogaster* can be a meeting point between those axes, becoming an excellent “educational compass” so that teachers have more clarity about which didactic paths to trace and undertake.

Final Considerations: *Drosophila melanogaster* in the crossroad between history, philosophy, sociology, and biology didactics

In a few words, our proposal is that historical, philosophical, and sociological studies of biology, regarding the *Drosophila*, they must be assumed as an ideal frame of reference so that teachers can support the nature of the science they intend to teach. We have seen that the educational literature consulted on the fly does not approach on these “meta-scientific” issues and can even go against them, which is evident with the ethical issues discussed, both in the field of scientific work in the laboratory, as well as in school practices around the *Drosophila*. We also allude to the nature of science as a field of inquiry and reflection of science education. It is from this perspective that we propose to understand *D. melanogaster* as a meeting point between the mentioned areas. Likewise, we consider, following Matthews (2017), that the nature of science can be understood as an educational compass that helps us locate ourselves and direct us towards the place of destination.

As was mentioned above, *Drosophila* is employed in biology teaching recurrently in practical and theoretical processes. However, in this article we defend that this organism, taking into account its historical, philosophical and sociological trajectory, presents a high potential to overcome an uncritical and instrumental approach of teaching process, and, in addition, it can promote a move away from a utilitarian conception of biology. This is how we propose an approach to the nature of science from the fly, given that its transfer as a model organism allows to demonstrate the complexity of scientific activity and what it demands for the subjects that are dedicated to its research.

Likewise, the meeting point represented by the *Drosophila* contributes to:

a) Understand the diversity of contexts in which progress is made and the value systems (ethical and epistemic, among others) under which different actions and practices are evaluated;

b) recognize the material and artefactual resources that were had or that resulted from work with the fly;

c) understand the motivations and the demands that the social context generated for its research, and the professional itineraries that they developed in the different areas in which that organism circulated;

d) have a better knowledge of the scientific methods and concepts and the way in which are associated with aims and values;

e) and promote the ethical discussion around the experimental practices beyond the field of genetics, due to the amount of natural and induced mutants of this species, but into other areas in which *D. melanogaster* plays a prominent role, such as the neurosciences, development biology, and, human diseases research, promoting protocols and regulations on its use in experimentation, and raising values of an ethical nature, which threaten not to treat living beings in a cruel or unworthy manner.

Thus, since this article deals with specific aspects of the teaching of biology, it would be opportune to refer particularly to the nature of biology, following Fischer, Wandersee and Moody (2002). These authors understand the biological knowledge and the nature of biology as a wide territory that, to be explored, requires that we have an adequate map:

> In learning about and traversing such a complex territory as biology, the metaphor of a map is useful. Mapping biology can help us see where we (and others before us) have been, and plot a route to our new destination via established referents, landmarks, and benchmarks. The alternative is accidental accretion of disorganized knowledge by random walk. However, if you want to get where you want to go, use a map! (Fischer; Wandersee; Moody, 2002, p. 32).

Of course, the *Drosophila* has not only allowed us to build genetic maps, it has also helped us to map and navigate the territory of biology and its teaching and, in this way, helped to integrate the scientific aspects with the "meta-scientific" and didactical aspects, it stands at the crossroads of those paths.

Like we have affirmed before, *Drosophila* have been a model organism of biology and its teaching, but, maybe the most relevant part for the proposal of this paper: This fly can also be a model to broaden the perspective on what we understand as the nature of biology, with clear didactical implications.

After all, the *Drosophila* has been part of various dimensions of our lives, and this dates back a long time. *Homo sapiens* and *Drosoph-*

ila melanogaster are both native to Africa and have spread over a good part of the planet. Perhaps we do not sail in the same boat, but we meet along the way, following the same routes: we have been fellow travellers and we have become together in an interspecies relationship (Castro; Bernal, 2021). Paraphrasing Kohler´s (1993), just as the "drosophilists" transformed the fly when it came to inhabit the ecology of the laboratory, this insect transformed Morgan and his team into a new breed of researchers; ultimately, it is a symbiotic interaction, thanks to which we have learned a lot about genetics and other areas of biology. Although the main lesson that we should have learned is focused on the ethical dimension of biology and its didactics: be respectful of other life forms and marvel at their existence. In our opinion, the fundamental course of biology teaching is to achieve this goal, where *Drosophila melanogaster* still has a lot to offer.

Received on April 29th, 2022
Approved on December 21st, 2022

Notes

1 Occasionally we allude to Drosophila, or simply like fly.

2 Indeed, it was not D. melanogaster but the housefly (*Musca domestica*), although Jacob uses that example to speak of the Drosophila as the first fundamental animal in the development of genetics.

3 Although it must be specified that our approach does not fully coincide with what the author expressed.

4 Although the generic name "*Drosophila* (dew-lover) was coined by the Swedish entomologist Carl Frederick Fallen in 1823 [...]" (Roberts, 2006, p. 93). Original English quote: "The name Drosophila (lover of dew) was coined by the Swedish entomologist Carl Frederick Fallen in (1823) […]

5 We will address the topic of educational environments in later sections, especially in the fourth.

6 "[…] – as the fly people [Morgan and his colleagues] called themselves –".

7 This trait is striking primarily because it is linked to sex, on the XY chromosome system.

8 In the Spanish version of this paper, all citations from English were translated by the authors.

9 According to Roberts (2006), *Drosophila melanogaster* can be considered as a model organism for more than 100 years.

10 For these authors, the term model organism has been widely used in biological discourses since the era of the human genome project and came to be part of the jargon of post-1980s science studies.

11 After the work of Morgan and his team, other researchers took up the *Drosophila* as an experimental organism and, due to this, understood aspects of heredity from molecular and developmental perspectives, among others. On this subject see Weber (2005; 2008).

12 The *American Biology Teacher* journal has a section entitled *How-to-do-it*, in which it is possible to find several practice papers that describe labora-

tory protocols that use the *Drosophila* for science teaching phenomena and concepts; for example, Mertens (1983), Heckman (1992), and Kurvink (2004), just to name a few.

13 From this citation, it can be inferred that biology teaching processes should promote caring for life, for which it is essential to have close contact with living organisms, avoiding treating them as mere instruments that can be manipulated at will. We will elaborate on this idea later.

14 The research of these authors was focused on high school students being able to understand the sexual behaviours of the *Drosophila*, mainly due to the interest that this topic arouses in adolescents and, also, because this type of activity does not require sophisticated equipment, such behaviours can be observed at a glance.

15 Although the project proposes strategies and resources (available online) that are interesting (for example, there are videos that explain why the fly has been used as a material for experimental research and activities that encourage students to develop graphs and statistical analysis), some of these activities promote non-humane use of flies, which is ethically reprehensible (see text and following notes).

16 Those aspects are not opposite, but complementary. We emphasize questions on science.

17 Izquierdo and collaborators (2016) invite, from the nature of science, to explore the teaching dimension that scientific activity has had at all times. Particularly, Morgan and his group propose a relevant educational practice reference to study.

References

ABRAHAM, Joel; PEREZ, Kathryn; PRICE, Rebecca. The Dominance Concept Inventory: a tool for assessing undergraduate student alternative conceptions about dominance in Mendelian and population genetics. **CBE – Life Sciences Education**, v. 13, n. 2, p. 349-358, 2014.

ADÚRIZ-BRAVO, Agustín. **Una Introducción a la Naturaleza de la Ciencia**: la epistemología en la enseñanza de las ciencias naturales. Buenos Aires: Fondo de Cultura Económica, 2005.

ANKENY, Rachel; LEONELLI, Sabina. What's so Special about Model Organisms? **Studies in History and Philosophy of Science**, n. 42, p. 313-323, 2011.

BAHAR, Mehmet; JOHNSTONE, Alex; HANSELL, Michael. Revisiting Learning Difficulties in Biology. **Journal of Biological Education**, v. 33, n. 2, p. 84-86, 1999.

BEALS, Ashlie; KRALL, Rebecca. Tried and True: inquiry-based environmental science investigations with the fantastic fruit fly. **Science Scope**, v. 33, n. 5, p. 66-69, 2010.

CASTRO, Julio. Conocimiento Práctico, Historia, Filosofía y Enseñanza de la Biología: el caso de la herencia biológica. TED – **Tecné, Episteme y Didaxis**, Bogotá, UPN, n. 34, p. 103-125, 2013.

CASTRO, Julio. El Estatus Ontológico, Epistemológico y Ético de los Animales de Laboratorio: del especismo a la biofilia y la bioética. **Tabula Rasa**, Bogotá, n. 32, p. 39-56, 2019.

CASTRO, Julio; BERNAL, Irma. Devenir Dingo: los límites difusos entre salvaje, feral y doméstico. Un abordaje teórico desde la etnografía interespecie. **Tabula Rasa**, Bogotá, n. 40, p. 199-223, 2021.

COLLEGE BOARD. **AP Biology Investigative Labs**: an inquiry-based approach. Canada: College Board, 2012.

DASTON, Lorraine (Org.). **Biographies of Scientific Objects**. Chicago: The University of Chicago Press, 2000.

DASTON, Lorraine; GALISON, Peter. **Objectivity**. New York: Zone Books, 2007.

DEMCZUK, Oxana; NUNES, Lenira; SILVA, Elgion. Investigação das Concepções Espontâneas Referentes a Ciclo de Vida e suas Implicações para o Ensino nas Series Iniciais. **Revista Electrónica de Enseñanza de las Ciencias**, v. 6, n. 1, p. 117-128, 2007.

DEMEREC, Milislav, KAUFMAN, Berwind. An Opportunity for Students of Heredity. **The American Biology Teacher**, v. 2, n. 8, p. 216-217, 1940.

FAUZI, Ahmad; RAMADANI, Shefa. Learning the Genetics Concepts through Project Activities using *Drosophila melanogaster*: a qualitative descriptive study. **JPBI – Jurnal Pendidikan Biologi Indonesia**, Malang, UMM, v. 3, n. 3, p. 238-247, 2017.

FISCHER, Kathleen; WANDERSEE, Jim; MOODY, David. **Mapping Biology Knowledge**. New York: Kluwer Academic Publishers. 2002.

GARCÍA-CARMONA, Antonio; VÁZQUEZ, Ángel; MANASSERO, María. Estado Actual y Perspectivas de la Enseñanza de la Naturaleza de la Ciencia: una revisión de las creencias y obstáculos del profesorado. **Enseñanza de las Ciencias**, v. 29, n. 3, p. 403-412, 2011.

GRILLI, Javier. El Material Natural en la Biología Escolar: consideraciones éticas y didáctica sobre las actividades prácticas de laboratorio. **Revista Eureka sobre Enseñanza y Divulgación de las Ciencias**, Cádiz, Universidad de Cádiz, v. 15, n. 1, p. 1104(01)-1104(19), 2018.

HARBOTTLE, Jennifer; STRANGWARD, Patrick; ALNUAMAANI, Catherine; LAWES, Surita; PATEL, Sanjai; PROKOP, Andreas. Making Research fly in Schools: *Drosophila* as a powerful modern tool for teaching Biology. **School Science Review**, v. 97, n. 361, p. 18-22, 2016.

HECKMAN, Robert. Teaching a Mendelian codominant *Drosophila melanogaster* Trait with Alcohol Dehydrogenase Allozyme Polymorphisms. **The American Biology Teacher**, v. 54, n. 8, p. 482-485, 1992.

INTRA, Jari; PASINI, Maria. The Fruit fly *Drosophila* as a Powerful Tool in Teaching life Sciences in Middle and High School Classrooms. **International Journal of Innovation and Research in Educational Sciences**, Bhopal, v. 3, n. 5, p. 288-295, 2016.

IZQUIERDO, Mercè; GARCÍA, Álvaro; QUINTANILLA, Mario; ADURIZ-BRAVO, Agustín. **Historia, Filosofía y Didáctica de las Ciencias**: aportes para la formación del profesorado de ciencias. Bogotá: Universidad Distrital "Francisco José de Caldas", 2016.

JACOB, François. **El Ratón, la Mosca y el Hombre**. Barcelona: Crítica, 1998.

KELLER, Andreas. *Drosophila melanogaster*'s History as a Human Commensal. **Current Biology**, v. 17, n. 3, p. R77-R81, 2007.

KOHLER, Robert. *Drosophila*: a life in the laboratory. **Journal of the History of Biology**, v. 26, n. 2, p. 281-310, 1993.

KOHLER, Robert. **Lords of the Fly**: *Drosophila* genetics and the experimental life. Chicago: The University of Chicago Press, 1994.

KOHLER, Robert. Moral Economy, Material Culture and *Drosophila* Genetics. In: BIAGIOLI, Mario (Org.). **The Science Studies Reader**. London: Routledge, 1999. P. 243-257.

KURVINK, Karen. *Drosophila* & Beer. An Experimental Laboratory Exercise. **The American Biology Teacher**, v. 66, n. 1, p. 40-42, 2004.

MATTA, Nubia (Org.). **La Mosca de la Fruta:** *Drosophila melanogaster* como organismo modelo en genética. Bogotá: Universidad Nacional de Colombia, 2010.

MATTHEWS, Michael. **La Enseñanza de la Ciencia**: un enfoque desde la historia y la filosofía de la ciencia. México: Fondo de Cultura Económica, 2017.

MAYER, William. Objectives of Animal Use in Biology Courses. In: McGIFFIN, Heather; BROWNLEY, Nancie (Org.), **Animals in Education**: use of animals in high school biology classes and science fairs. Washington: The Institute for the Study of Animal Problems, 1980. P. 11-16.

MERTENS, Thomas. Open-ended Laboratory Investigations with *Drosophila*. **The American Biology Teacher**, v. 45, n. 5, p. 264-266, 1983.

MORIMOTO, Juliano; PIETRAS, Zuzanna. Natural History of Model Organisms: the secret (group) life of *Drosophila melanogaster* larvae and why it matters to developmental ecology. **Ecology and Evolution**, n. 10, p. 13593-13601, 2020.

NISSANI, Moti. Dancing Flies. A Guided Discovery Illustration of the Nature of Science. **The American Biology Teacher**, v. 58, n. 3, p. 166-171, 1996.

ORTIZ, Gustavo. Víctimas de la Educación: la ética y el uso de animales en la educación superior. In: RIVERO, Paulina (Org.). **Zooética**: una mirada filosófica a los animales. México: Fondo de Cultura Económica, 2018. P. 214-241.

PAGE, Robert; CROOK, Matt. Investigating Causal Genetic Variation in the Yellow Gene of *Drosophila melanogaster* as a Means of Teaching Foundational Molecular Genetic Concepts & Techniques. **The American Biology Teacher**, v. 84, n. 1, p. 28-32, 2022.

PALOUMPIS, Andreas. The Use of *Drosophila melanogaster* in High School Genetics. **The American Biology Teacher**, v. 15, n. 8, p. 213-216, 1953.

PASINI, Maria; BERTOLOTTOA, Francesca; FASANO, Paola. The Role of Models in Science: an experience with *Drosophila*. **Procedia Social and Behavioral Sciences**, n. 2, p. 1164-1168, 2010.

PLUNKETT, Andrea; YAMPOLSKY, Lev. When a Fly has to Fly to Reproduce: selection against conditional recessive lethals in Drosophila. **The American Biology Teacher**, v. 72, n. 1, p. 12-15, 2010.

ROBERTS, David. *Drosophila melanogaster*: the model organism. **Entomologia Experimentalis et Applicata**, Wageningen, n. 121, p. 93-103, 2006.

SNUSTAD, Peter; SIMMONS, Michael. J. **Genetics**. New Jersey: Wile, 2012.

SOFER, William; TOMPKIN, Laurie. *Drosophila* Genetics in the Classroom. **Genetics**, n. 136, p. 417-422, 1994.

WEBER, Marcel. **Philosophy of Experimental Biology**. New York: Cambridge University Press, 2005.

WEBER, Marcel. Experimentation. In: SARKAR, Sahotra; PLUTYNSKI, Anya (Org.). **A Companion to the Philosophy of Biology**. Oxford: Blackwell Publishing, 2008. P. 472-488.

Julio Alejandro Castro Moreno he is a professor and researcher at National Pedagogical University of Colombia, affiliated to Biology Department and the Interinstitutional Doctorate in Education. Has a degree in Biology for District University "Francisco Jose de Caldas" (Bogotá) and a Ph.D. in Philosophy of Science for the National Autonomous University of Mexico. His interest areas are the relations between history, philosophy, and didactics of biology, in teacher training.
ORCID: https://orcid.org/0000-0002-5864-0954
E-mail: jcastro@pedagogica.edu.co

Irma Catherine Bernal Castro she is a professor and researcher at National Pedagogical University of Colombia, affiliated to Biology Department. Has a degree in biology for National Pedagogical University of Colombia and has a master's and Ph.D. in philosophy of science for the National Autonomous University of Mexico. Her interest areas are the relations between history, philosophy, and social studies of biology, didactics and biology teaching, and the evolution of sociability.
ORCID: https://orcid.org/0000-0003-1912-0312
E-mail: icbernalc@pedagogica.edu.co

Editors in charge: Luís Henrique Sacchi dos Santos; Leandro Belinaso Guimarães; Daniela Ripoll