Educação & realidade

# Learning by Drawing: successful experiences in the scientific and artistic training of pre-school teachers

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**ABSTRACT – Learning by Drawing: successful experiences in the scientific and artistic training of pre-school teachers.** This reflective work is based on a theoretical framework on the role of drawing in science and its potential as a learning strategy. Two successful educational experiences with students on the degree course in early childhood education at the University of Valladolid (Spain) are described: one for the study of insects, and another for the study of plants. Under an artistic approach, students learned biological science content, improved their artistic graphic skills, and modified their initial attitudes of rejection and indifference towards the studied organisms. Finally, we reflect on the didactic possibilities of drawing and the shortcomings in research located at the intersection of art and science in education, an emerging field to which it is necessary to contribute through joint research.
Keywords: **Drawing. Science Education. Art Education. Initial Teacher Training.**

**RESUMEN – Aprender Dibujando: experiencias exitosas en la formación científica y artística de maestros de infantil.** Este trabajo de reflexión parte de un marco teórico sobre el papel del dibujo en la ciencia y su potencial como estrategia de aprendizaje. Se describen dos experiencias educativas exitosas con estudiantes de Grado en Educación Infantil de la Universidad de Valladolid (España): una para el estudio de los insectos y otra para el de las plantas. Bajo un enfoque artístico, los alumnos aprendieron contenidos de ciencias biológicas, mejoraron sus habilidades artístico-gráficas y modificaron sus actitudes iniciales de rechazo o indiferencia hacia los organismos estudiados. Por último, se reflexiona sobre las posibilidades didácticas del dibujo y las carencias en investigaciones situadas en la intersección arte-ciencia en educación, un campo emergente al que es necesario aportar investigación conjunta.
Palabras clave: **Dibujo. Didáctica de las Ciencias. Educación Artística. Formación Inicial de Maestros.**

## Introduction

Throughout history, many and varied links have been established between art and science. It is noteworthy that both fields of knowledge have felt the attraction of the mysteries of nature and have striven, from their own particular perspective, to unveil its internal order. Observation and analysis, frequently of formal questions, such as the form-function relationship or the changes in appearance of natural elements over time), are essential skills in both disciplines. Both art and science focus on nature and the laws that govern it, or from a strictly artistic viewpoint, the principles on which it is formally structured. Art, however, goes beyond this perspective to delve into nature's influence on human emotions, because nature calms and cures. It is the *locus amoenus*, the quintessential place of pleasure, and, since the emergence of Romanticism, it has become the mirror of our feelings of melancholy and sadness or of unleashed passions. This latter perspective is undoubtedly far removed from the scientific one, which is characteristically oriented towards reasoning and quantification. It is also true, nonetheless, that we increasingly hear references to issues such *as nature-deficit disorder*, to how art can help us see the small *miracles* that typically go unnoticed, thus enhancing our psycho-emotional wellbeing. Art can also serve to appreciate the hidden beauty of elements or processes that, *a priori*, we consider to be intrinsically ugly (Driessnack, 2009; Louv, 2010; Pouyet, 2009). In this way, aesthetics, an eminently artistic topic and a field of study in itself, can be considered a relevant aspect of science teaching, which also has additional cognitive and psychological benefits for students at different educational stages. In this bidirectional and reciprocal relationship, drawing derived from the study of reality is deeply nourishing for artistic thought. As explained by López Fdez.-Cao (2015, p. 87), drawing involves the need to look carefully, keenly, intensely and affectively, it even entails "listening to the environment, knowing its rules, noting them, understanding the structures and participating in them by means of our hands and fingers."

## Theoretical framework

### *Drawing as a Descriptive Discipline in Science*

Science has always needed to record data from the observation of nature. In recording such observations, the role of the image is as important as that of the word, as it allows us to detect patterns and structures (Katz, 2017) and also avoids excessively detailed texts, completing and increasing their meaning (Cabezas; López, 2016). Although scientific representation has not been without certain reservations throughout history, considering the image to be overly dependent on the skills of the drawer, the effectiveness of technical resources available for its reproduction and even the iconographic tradition in which it is situated (Ivins, 1975), the utility and scope of drawing as a means of faithful representation are currently beyond any question (Baidal et al., 2022).

It is worth noting that *iconism*, or the systematic scientific representation of natural elements, was primarily developed as a result of colonial scientific explorations, particularly those implemented on the American continent (Cabezas; López, 2016). It was then that it became essential to define and name unfamiliar elements as it was evident that it was insufficient to say that a plant or animal was similar to one from Europe; it was necessary to study and settle the new knowledge acquired (Amaya; Puig-Samper, 2009). This resulted in the creation of large collections of illustrations, where the exotic iconography underlined the scientific ideas and cultural parameters of the time, with the drawings being a source of artistic inspiration and a means of raising public awareness of the work of exploration (Attenborough et al., 2017).

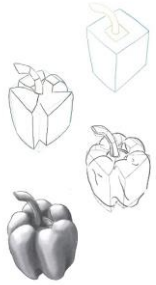
Furthermore, as explained by Ivins (1975), the code for descriptive graphic representation was conceived from the tension between two general theoretical ideas, the opposition of which progressively shaped the direction of drawing in science. On the one hand, there were those in favor of portraying each specific individual, which entailed virtuously recreating all the specimen's details (in the case of plants, for example, including dried or insect-bitten leaves in the drawing). On the other, there were artists and schools whose work, consciously or not, was oriented towards depicting *types* or standardized representations of each species, avoiding any circumstantial particulars that might affect specific specimens. It was the latter option that eventually prevailed, following passionate debates on how to unequivocally recreate all the aspects of the natural element to be described (in the case of plants, not only the stem and foliage, but also the upper side and underside of the leaves, their flowers, roots, fruits and seeds).

Making a graphic generalization that was good enough to allow for the recognition of any individual of the same species was no easy task; on the contrary, it entailed a high level of analysis and interpretation that was only possible after a rigorous study. It was also necessary to collect different specimens in different seasons or developmental stages. Exhaustive observation, comparison, measurement and, in short, formal analysis, together with the compositional principles that produced a harmonious configuration of the illustrations, constituted the essence of this type of graphic work.

### *Principles of Scientific Drawing and Differences from Other Forms of Art in Science: Scientific Illustration and Naturalistic Drawing*

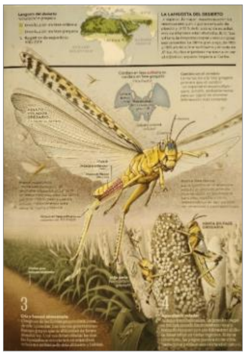
From an artistic point of view, the analysis of specimens carried out in scientific drawing focuses mainly on structural aspects, which may entail the elimination of repetitive elements, but also of those features that are considered excessively variable or superficial. This is the case of color, which has been omitted from botanical keys and is also practically absent from entomological scientific drawings. Science is legitimately interested in the bare form, divested of elements that might cause distraction. Moreover, it favors an undeniable visual tendency towards what might be called *essential form*, that which has a geometrical ideal as its reference. For this reason, we cannot fail to emphasize how, for the sake of maximum objectivity, the creation of an iconographic type always implies a certain level of abstraction (Figure 1). In short, today's scientific drawing is highly codified; there may be no color, rarely are elements superimposed or specimens of different species represented on the same medium.

**Figure 1 – Example of an exercise from *Manual of Scientific Illustration***



Source: Baidal et al. (2022, p. 54).

**Figure 2 – Illustration from National Geographic**



Source: National Geographic (2022).

Scientific illustration holds a different approach, since, despite being governed by the ideals of verisimilitude and representativeness, it is oriented towards dissemination and raising awareness among the general public, seeking to accessibly transmit scientific knowledge. In this sense, aesthetics are important, but, as noted by Baidal and Cerviño (2017, p. 27): “While illustrations must be visually pleasing to capture the viewer’s attention, aesthetics *per se* takes second place”. Meanwhile, the primary aim of naturalistic drawing is the personal recording of observations, predominantly in the field notebook, combining the drawer’s experience and artistic sensitivity “moving between the plastic arts and natural sciences, between empirical knowledge and that spiritual channel of artistic activity that connects human beings with nature” (Ortega-Alonso, 2018, p. 142). Both disciplines are heirs to the tradition of the artist's study of nature and merge scientific and artistic knowledge, such that color and composition are crucial to arouse sensitivity and, through it, knowledge, even if it is not expert knowledge (Figure 2).

## *Drawing as a Tool for Learning*

Recent years have seen the publication of several important studies on graphic language as a fundamental element in learning. Moline (2011) underlines the use of graphic representations as an element of mediation between content and student, at different educational levels, highlighting the increasingly necessary acquisition of a *visual culture* that helps students, from an early age, to discriminate between different types of representations. This is an essential question at a time when an infinite stream of images is just a mouse click away, which directly impacts students’ selection of references. In this sense, not all images are suitable for scientific learning, and/or are interesting from an aesthetic perspective, which also affects their educational potential, and so teachers recommend graphic work that focuses on the structural elements, running parallel to a specific process of *visual literacy* within the field of sciences.

A number of authors have addressed the potential of students’ own drawings as a means for learning. The most advanced studies have been conducted under the theoretical framework of *generative learning*, proposed by Wittrock in the 1970s, which, in turn, draws on Paivio’s dual coding theory and the constructivist theory developed by Piaget and Vigotsky. Derived from this approach, it is worth highlighting the more recent *SOI model* proposed by Mayer, which holds that meaningful learning takes place in three phases (selecting, organizing and integrating). This model serves as the theoretical framework for the analysis of diverse learning strategies, among which is that of drawings created by the students themselves. This strategy is considered effective in facilitating both comprehension and memory, while also having a series of further benefits, which, however, are only generated under specific conditions (Fiorella; Mayer, 2016).

One of the advantages of having students draw, from a learning perspective, is that drawing can be used at any age (Fiorella; Mayer, 2016), even with very small children (Dai, 2017), or with those with impaired communication (Holliday et al., 2009). In addition, drawing serves to evidence what students know about a particular topic, and is particularly revealing when the topic is spatially complex. In a well-known study by Giordan and De Vecchi (1988), students' drawings were used as the means to reveal their personal conceptions of different scientific topics, allowing them to explain their prior ideas and being an important step towards the construction of more sophisticated mental models. This pioneering educational research led to the conception of drawing as an effective means for bringing students' ideas to light, ideas the teacher needs to know so they can work on them (Carvalho; Cardoso, 2019; Bartoszek; Tunnicliffe, 2017; Tunnicliffe; Sarker, 2017; Villarroel et al., 2018). It is worth noting here that, in the paradigmatic literature on spontaneous drawing, particularly in the case of children, drawing was always considered an ideal path through which to learn how a student thinks (Machón, 2009).

Furthermore, students' drawings have also been used to observe improvements in their scientific knowledge stemming from specific educational interventions. For example, Cainey, Humphrey and Bowker (2017) used the technique to see what a group of schoolchildren learned about marine life following an aquarium visit, while Stears and Dempster (2017) used it to observe the development of anatomical knowledge at school, and Jose, Patrick and Moseley (2017) as a means to measure change in knowledge after a secondary school field trip. Additionally, various works suggest that drawing can be a powerful tool for personal study in science. In this regard, it is worth highlighting the works by Anderson, Ellis, and Jones (2014); Ainsworth, Prain, and Tytler (2011); Babaian and Kumar (2022); Chang (2017); Gómez and Gavidia (2015); Sanders (2007); and Tytler et al. (2019), all of which underscore the potential of drawing to build concepts and generate knowledge, particularly when students are required to study content they find complex. The utility of drawing in science learning science appears to lie particularly in the careful observation students that draw are obliged to engage in, as reported in the studies by Tishman (2018), part of the Harvard Zero Project, and by Anderson (2019), a resident artist at London's Imperial College, the general line of argument of which, in both cases, aligns with the classic drawing method proposed by Edwards (2011). In other words, learning to draw – and thus discovering and internalizing information while drawing – entails, above all, a way of looking that is characterized by "epistemological commitment" (Tishman, 2018, p. 123). Such ideas are supported by Van Meter and Garner (2005), who find that drawing helps to see details and appreciate the subtle differences between natural specimens, which is a critical skill in scientific study, as well as facilitating comprehension of texts and writing processes. Meanwhile, in a recent review article, Fan et al. (2023) endorse the above ideas, highlighting how drawing is associated with improvements in cognitive and perceptive tasks, although the education conditions required for its successful implementation have yet to be determined.

Notwithstanding, very few studies in the field of science have considered drawing as a language that is subject to its own rules, which implies a certain questioning of the degree of accuracy of the interpretations that are made of the graphic transcriptions of personal internal conceptions. Occasional references can be found in studies such as that by Neumann and Hopf (2017), who, in their work on children's science associations, recognize that some students tend to choose simplistic representations, inhibiting their spontaneous ideas, while Nyberg and Sanders (2013) discuss the influence of affective experiences on representations. Moreover, other studies report that the robustness and scope of the knowledge acquired greatly depend on the quality of the drawing itself (Van Meter; Garner, 2005), and that, reaching a certain level, requires investing time and the guidance of a specialist teacher (Dempsey; Betz, 2001; Fiorella; Zhang, 2018; Van Meter; Garner, 2005). Furthermore, Fiorella and Mayer (2016) suggest that drawing contributes to the development of higher-order cognitive strategies, which are difficult to detect through conventional tests. Finally, Fiorella and Zhang (2018) underline that, despite there being a long tradition of shared work between science and art, the type of collaboration needed to develop appropriate graphic skills in students rarely occurs.

Although the questions referred to in the paragraph above are common knowledge for any teacher of artistic expression, it is interesting that they have begun to be considered in other areas of knowledge, especially if a fruitful collaboration is to be established in the emerging educational intersection of art and science, where more research is needed (Chang et al., 2020; Fan et al., 2023; Fiorella; Zhang, 2018; Fiorella; Jaeger, 2023; Tytler et al., 2019).

## Experiences in Pre-Service Teacher Training

Teachers of all educational levels are considered agents of change, that is, individuals that can catalyze the successful introduction of innovations or new perspectives in society (Brown et al., 2021). It is thus particularly crucial for future teachers' pre-service training to be well-grounded in the different fields of knowledge, in terms of both the discipline and its didactics. In the case of the natural and experimental sciences, this objective is an arduous task, since students that opt to study for degrees in early childhood or primary education in Spain generally neglect science specialties in their higher secondary education, often expecting not to have to study them again (Solbes, 2011; Esteve; Solbes, 2017). Consequently, teachers are forced to find ways to engage such students in learning sciences, given that they will have to teach them to future generations.

*Context-based science teaching*, that is, using the context and applications of science to develop scientific understanding, has been one of the most significant trends in building science curricula over the last three decades (Bennett et al., 2007; Fensham, 2009). As well as bolstering learning, this strategy helps enhance the relevance of the scientific knowledge being taught, motivating students and improving their attitudes towards science and its study (Bennett et al., 2007). This trend is related to *situated learning*, a concept that originated in arts education, and aligns with its essential principle of harnessing any educational opportunity to meaningfully incorporate an artistic perspective (Eisner, 2004). Relatedly, *artistic perspective* is defined as a substantially deep, sensitive and aesthetic vision of reality, where *the aesthetic* is understood as the opposite of *the anesthetic*, that is, a heightened visual capacity, far removed from the dulling of senses and numbness of feeling (Eisner, 2004, p. 109). The use of organic learning gardens has recently been proposed in order to contextualize the teaching of different scientific and environmental education topics in pre-service teacher training (Eugenio-Gozalbo et al., 2022), which is also related to the early concern of arts education with environmental education (Martínez et al., 1995). Moreover, it was during the design of contextualized teaching-learning sequences in the university garden that the idea of incorporating drawing as a strategy to promote observation and access to beauty emerged, being an attempt to enhance the learning of certain science topics and to refine students' perceptual and graphic skills.

## *Insects, Those Strange Little Beings*

In the 2018/2019 academic year, we decided to address teaching and learning about insects in the setting of the university garden. Insects (arthropods in general) are insects that arouse curiosity and fascination in young children due to their particular morphological characteristics (Shipley; Bixler, 2017). However, they are barely touched upon in early childhood and primary education (apart from the activity of breeding silkworms to teach life cycles), because teachers tend to dislike them. In adults, these animals often evoke feelings of dislike, disgust or fear. This is because some of their features appear threatening or unpleasant (stings, mouthparts, thick hairs) (Bixler; Floyd, 1999), and because many individuals have had painful experiences and/or negative social learning regarding insects (Breuer et al., 2015), with some people even having developed more intense emotional reactions, such as phobias (Gerdes et al., 2009). Nevertheless, it is important for teachers to work on insects in schools, because they are the most abundant and biologically diverse group of organisms on the planet, are crucial to food chains, perform essential functions in ecosystems, and are in unprecedented decline (Sánchez-Bayo; Wyckhuys, 2019).

To tackle these obstacles to learning, which are related to the visual characteristics of insects and the emotions they provoke, we decided to approach their teaching using a strategy that would encourage both observation and the generation of new experiences with live insects. To this end, we designed a didactic sequence whose objective was to foster knowledge and appreciation of insect biodiversity (Eugenio-Gozalbo; Ortega-Cubero, 2022). Drawing on the emotions and knowledge our students expressed, we developed a series of activities focused on observing and perceiving beauty, for example, watching a documentary (Microcosmos, 1996), and using clues to identify the inhabitants of the compost, among others.

The two most noteworthy activities in the sequence were a scientific insect drawing seminar, carried out in the classroom, and a final naturalistic drawing session in the learning garden, during which the students drew the insects living there and identified them using guide books. At the beginning of the sequence, we asked a group of 28 pre-service pre-school teachers to draw 5 insects from memory. We obtained an extensive sample of drawings with the characteristic formal schemes of children's drawings, a type of graphic expression which is natural not only to children but also to adults without artistic training (Edwards, 2011). These drawings were frequently unspecific or incorrect in terms of morphology, omitting features that are structurally relevant but play no role in their visual recognition. They also included animals that are not insects (other *bugs*), with very different types of bodies (such as slugs, earthworms or worms) (Figure 3).

**Figure 3 – Example of the type of drawing the students initially produced**


Source: Authors' own photograph.

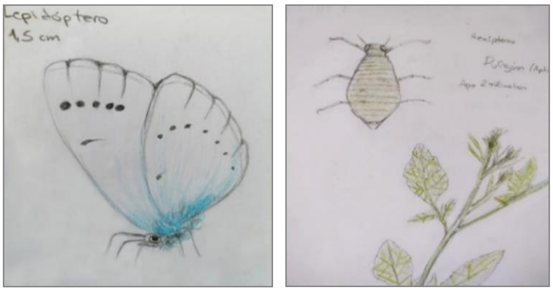
The scientific drawing session was conducted with small groups of students (around 12), such that the art teacher would be able to closely supervise the activity. There was a short theory class in which the most significant aspects were introduced (block-in, symmetry, proportion etc.) and then each student was given a specimen. These were chosen, following aesthetic criteria, from the National Geographic *Bugs* Collection, which was considered appropriate for the task as it includes organisms of a good size (normally of tropical origin) and conserved in methacrylate cases, thus facilitating the observation of their morphological features. After the two-hour session, we obtained surprisingly beautiful and anatomically correct drawings (Figure 4).

**Figure 4 – Drawings produced following a scientific drawing session conducted by an art teacher in closely supervised small groups**

Source: Author's own photograph.

To close the sequence, we implemented the naturalistic drawing session in the learning garden. A sunny day was chosen with good temperatures (this being important for insect activity), and the students, organized in groups of 4, were asked to search for 5 different insects. They identified them taxonomically with the help of the science teacher, and then sketched them individually (not going into great detail; just reflecting the most significant morphological characteristics). They were also asked to make a note of any significant aspects of the environment in which the insects were found. They were invited to capture the specimens in a humane way (using an insect vacuum catcher) and place them in observation jars. On this occasion, the students produced drawings in which the key morphological features (proportions; division of the body into head, thorax and abdomen; segmented appendages; six legs) were correctly represented in most cases (Figure 5). This should be considered a positive outcome of the scientific drawing training seminar, as these animals' small size and constant movement make them difficult to observe and draw from life.

**Figure 5 – Examples of naturalistic drawings produced in the university garden**




Source: Authors' own photographs.

The abundant graphic material collected throughout the sequence was evaluated by means of the constant comparative method used in grounded theory and a rubric specifically designed for this purpose. The rubric focused on the assessment of structural aspects (body symmetry, division of body into three segments, correct number of legs, and proportional accuracy) as well as certain artistic qualities of the representation, such as color, texture, and the sense of volume (Annex). Meanwhile, the constant comparative method involved the intensive and recurrent comparison of corpus of graphic for the purpose of establishing analytical categories (Corbin; Strauss, 2015). Both instruments yielded excellent results (Eugenio-Gozalbo; Ortega-Cubero, 2022), showing great progress in both knowledge and the appreciation of insect diversity. Several elements contributed to this success, particularly the visually centered strategy designed to foster observation, enabling students to overcome their initial reticence, distinguish the major taxonomic groups and eventually to be able to appreciate the beauty of these animals through art.

## *Plants: not seen, not recognized, not valued*

More recently, in the 2022/2023 academic year, we decided to address teaching and learning about plants in the university learning garden. We are often surrounded by plants and a large part of our diet is based on their cultivation. However, we frequently ignore the presence, identity and characteristics of the plants around us. These questions are at the center of a well-established debate among science educators, particularly since the coining of the term *plant blindness* (Wandersee; Schussler, 1999). Children do not find plants especially interesting because they make no sounds nor do they move (Yorek et al., 2009). However, they should be taught in pre- and primary school, not only because they are part of the curriculum but also because of the quantitative and functional importance for our planet. Among other key ecological functions, plants are primary producers (Grime, 1998), and their current extinction rates are high, particularly in regions with a tropical or Mediterranean climate (Humphreys et al., 2019). It is worth noting that, despite plants being studied at various stages of formal education, they are a scientific topic on which meaningful learning is difficult (Özay; Öztaş, 2003).

As an approach to teaching and learning about plants, we decided to design a didactic sequence incorporating drawing, with the aim of promoting their observation, such that it would be easier to address the scientific questions of morphology (parts and vocabulary to name them) and taxonomy (classification into large evolutionary groups and families), and also the appreciation of their beauty. The sequence was implemented with a group of 40 pre-service pre-school teachers and included two drawing sessions. The first consisted of taking sketches from life in the setting of the garden, on a freely chosen plant, and under the supervision of the art teacher, which allowed for a certain distancing from the graphic stereotypes for representing plants, although the drawings still contained formal errors (Figure 6). The second entailed a seminar on botanical illustration, as we considered this specialty aligned better with our purposes than did scientific drawing – being more rigorous and focused on highlighting the specific characteristics used to identify species, while also facilitating a more natural connection with the beauty of plants.

**Figure 6 – Examples of naturalistic drawings made in the university garden**


Note: In the almond tree, the thin branches are incorrectly drawn and the flowers on the tree are stereotypical. Nonetheless, if it is worth comparing with Figure 9, which shows the type of drawings produced by the students at the start of the learning sequences. Source: authors' own photographs.

The botanical illustration seminar included a brief introductory theory class, and again the students were invited to choose a plant, which they took to the classroom to draw from life. This activity was partly analyzed using the constant comparative method and also a specific rubric. The results show that all of the 20 randomly selected students were able to appreciate the essential formal aspects (general structure of the specimen, form of the leaves, general appearance of the flowers, and, if relevant, roots, fruits, seeds or other elements of interest), avoiding graphic stereotypes and incorporating details of color and texture (Figure 7).

**Figure 7 – Drawings produced following a botanical illustration session conducted by an art teacher in closely supervised small groups**

Source: Authors' own photographs.

The sequence also included other activities with a visual focus: intuitively drawing and classifying some of the plants in the garden, observing them under a magnifying glass or microscope (anatomy), and exploring non-fiction picture books and books with striking photographs, which students could consult during the practical sessions. Some of these tasks were conducted at the Faculty of Education in Soria in the science and art classroom specifically designed for children (Figure 9), which has the Spanish acronym of ALICYA (Children's Science and Art Laboratory-Classroom). This newly created space has the dual purpose of inviting schoolchildren from the city to enjoy activities and offering university students the possibility to participate directly in the design, organization, and implementation of such activities, and in the development of related research projects (Figure 8).

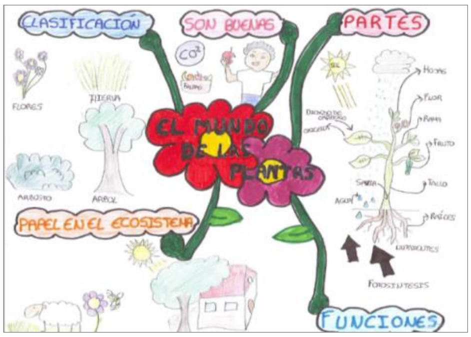
**Figure 8 – Children's science and art laboratory-classroom (ALICYA)**

Source: Authors' own photograph.

Once the sequence was completed, the students' learning progress was assessed through, among other factors, the use of mental maps which they were asked to produce at the beginning and end of the sequence. This tool combines the use of text and images to structure and present what an individual knows about a certain topic, which aligns perfectly with the visual focus of the learning we were aiming for. From a total of 40 initial mind maps and 40 final ones, we randomly selected 50% for analysis. These were studied using the grounded theory constant comparative method and a specifically designed rubric, which considered various graphic and content-related dimensions. The graphic analysis of the material took into account the general compositional structure, the balance between text and image and the richness of the drawing. Four levels were established, from the lowest (the student does not draw, or only includes drawings as a compromise solution, with an excessive number of graphic stereotypes), to the highest (the student includes a finely-detailed personal drawing, based on observation). Finally, the change between the initial and final mental maps was qualitatively assessed, establishing three levels of change: low (the student repeats the same ideas and the graphic representation); medium (the student has acquired new knowledge, which is better organized and expressed than in the initial map, and the drawing quality has increased); and high (the student has acquired notable new knowledge, which is better organized and expressed than in in the initial map, and the drawings are finely detailed).

The initial mental maps (Figure 9) revealed scant knowledge of the plant world, a tendency to represent knowledge through graphic stereotypes, and misconceptions about types of vegetation (flowers are considered at the same level as grasses, bushes and trees, for example) and physiology (particularly in terms of nutrition and respiration).

**Figure 9 – Example of initial mental map, showing graphic stereotypes of a flower and tree**




Note: Additionally, the students include flowers in the same classification as grasses, bushes and trees. Source: authors' own photograph.

In contrast, the final mental maps included more information nodes (that is, they represent more areas of knowledge) and more connectors (establishing more relationships between elements); there was also a greater amount of high-quality information in each node. Significantly, of a total of 20 mind maps analyzed, none showed a low level of change, while 7 maps showed a medium level of change and 13 a high level. It is worth noting that, in general, even in the final maps with a medium level of change, the drawing was much more reflective: the plant structures are distinguished and represented more finely, reflecting what the students observed, which does not conflict with the use of stereotypes to quickly communicate generic ideas.

## Conclusions

Both the theoretical framework used in this work and our own experiences with the pre-service pre-school teachers support the notion that drawing is a good way to learn natural sciences. Moreover, the shared interest of art and science in the study of elements such as plants, animals, minerals, landscapes, and atmospheric phenomena, as well as a long tradition of joint work, means that the association between the plastic arts and natural sciences is also logical and natural in the field of education.

However, the mere act of drawing does not necessarily imply the construction of substantial knowledge, neither in one subject nor the other, when the teaching conditions are not appropriate. It has been seen that learning depends, to a great extent, on the students' level of graphic proficiency (Van Meter y Garner, 2005), for which specialized art education is essential (Fiorella; Zhang, 2018; Van Meter; Garner, 2005), as is close collaboration between art and science teachers (Dempsey; Betz, 2001). We also know that the outcomes achieved through drawing are substantially different from those delivered by other didactic tools, and that such results are difficult to determine by means of conventional tests (Fiorella; Mayer, 2016). Both Mayer's SOI model (Fiorella; Mayer, 2016), as well as works that point in the direction of developing an epistemologically-committed approach (Anderson, 2019; Thisman, 2018), are consistent with established methods of drawing from life (Edwards, 2011) and indicate deep learning by students who draw.

In our experience on insect drawing, having graphically studied the morphology of these animals clearly allowed the students to make accurate drawings from life, even using living, small, and moving specimens. This question is undoubtedly associated with the development of higher-order cognitive strategies to which our theoretical framework points (Fiorella; Mayer, 2016), and is related to acute, sensitive perception, which favors the identification of natural rules and the internalization of the structures of the natural world (López Fdez.-Cao, 2015). A similar outcome emerged with plants, as the didactic sequence generated, among other things, a much deeper and more detailed knowledge of plant morphology on the part of the students.

Apart from the above points, perhaps the most impressive aspect of these experiences is the change in the students' own consideration of the organisms being studied. The graphic medium is ideal for showing elements that are not typically observed, because they are not paid attention to, and for discovering beauty, even when it seems absent at a superficial glance. Hence, it is concluded that drawing is ideal for overcoming the students' rejection of certain scientific subjects, encouraging their commitment to the discipline (Ainsworth; Prain; Tytler, 2011). A further conclusion is that the models offered by nature could not be more apt for awakening the students' artistic sensitivity (Edwards, 2011). Moreover, in a world where the imagination of children and young people is shaped, at least to a large extent, by what they see on screens, direct contact with natural models appears increasingly important (Louv, 2010), particularly through a mode of observation that demands all of one's attention (Eisner, 2004; López Fdez.-Cao, 2015). In addition to this, the visual culture of future teachers is expanded through a process of visual literacy inherent in the work undertaken, which may help reduce the unreflective selection of visual references directly extracted from the Internet (Moline, 2011).

Another interesting outcome of these didactic proposals was that the world of our students grew in scope, both in a more abstract sense, of knowledge, and in a more practical sense, of perception. For example, in their conceptions, "the beetle" ceased to exist, becoming the churchyard beetle (which is usually found in the composters), the red soldier beetle (pollinators in the orchard), or the stag beetle (which the students saw in the National Geographic collection), among others. Meanwhile, in the garden, they stopped seeing only plants and soil, and began to see (and appreciate) a great diversity of small beings, which they did not notice before. This is one of the wonders that emerges from training in observation, as both naturalists and artists know well.

Finally, we should address the question of how spontaneous drawing can shed light on students' knowledge around various topics. There are gaps in the literature in this regard, as very few science articles query the power of drawing to reflect the physical world or consider drawing as a language with its own rules that model representation (Newmann; Hopf, 2017; Nyberg; Sanders, 2013). In the field of art education, however, it is well established that drawing is subject to perceptual, formal, developmental, aesthetic, and emotional constraints, which mean it cannot be taken as a literal transcription of students' prior ideas or knowledge, even though it may offer useful insights (Machón, 2009). We believe that art teachers, who well understand spontaneous expression, can make a necessary contribution in this sense, because, as the literature suggests, further research is needed (Fan et al., 2023; Chang et al., 2020; Fiorella; Zhang, 2018; Tytler et al., 2019).

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