JOURNAL OF BIOLOGICAL EDUCATION
https://doi.org/10.1080/00219266.2023.2192732

Conceptions of primary school students and trainee teachers about seed germination

Beatriz Carrasquer-Álvarez and Adrián Ponz-Miranda

Department of Specific Didactics, University of Zaragoza, Zaragoza, Spain

ABSTRACT
Research into seed germination classroom activities has been common in the last few decades. Didactic proposals have generally focused on the implementation of guided activities in a specific educational stage and context, and an evaluation of the results. However, it is not evident that students approach seed and germination concepts with a reasoned argument. In light of this, comparative research using an inquiry approach was undertaken with 59 primary school students and 82 trainee teachers at an education faculty in Spain, over two academic years. The results showed that it is necessary to give greater relevance to experimental activities to produce reasoned argumentation of seed and germination concepts. Activities should focus on variables that differ from those typical of common or historical agricultural knowledge. Variables derived from genetic information (size of the seed, latency period) are significant and helpful. It is also considered essential to work on the meaning and proper use of scientific terms, such as living and inert matter, sun-light-heat, or plant germination and growth processes. The search for explanations and the development of justifications, for example relating the excess of water to a lack of oxygen for the seeds, is also essential.

ARTICLE HISTORY
Received 1 February 2022
Accepted 27 January 2023

KEYWORDS
Seed germination; primary school students; trainee teachers; inquiry; comparative research

Introduction

Agriculture has long been associated with people's culture and linked to humans' cognitive and social development. More recently, didactic proposals about seed germination started to be included as a common practice in classrooms at different educational levels, beginning from an early age (Cherubini, Gash, and McCloughlin 2008; Hammann et al. 2008; McEwen 2007). Species such as legumes and grasses are used because of the simplicity of acquiring them, the relative speed of the vegetative evolution of the seeds and the high degree of success. Additionally, a solid knowledge of the biological processes or factors involved in their germination is not needed (Vidal and Membiela 2014). According to Chaves (2016), some educational concepts must have certain characteristics to be relevant within its discipline or teaching and therefore also of educational importance. In addition, concepts are used with different senses (polysemy) in the same or other disciplines, and may also have more symbolic meanings. The concept of seed germination meets some of these requirements (educational importance, polysemy), especially when linked to the concept of life (Bachellard 2000; Coutinho, Martins, and Menezes 2011; Gayon 2010; Mortimer and El-Hani 2014). Therefore, a review of seed and germination concepts, models and didactic proposals is presented next, as is a comparative study using an inquiry approach for assessing understanding of seed germination concepts by primary education students and teacher trainees.

CONTACT Beatriz Carrasquer-Álvarez becarras@unizar.es
Supplemental data for this article can be accessed online at https://doi.org/10.1080/00219266.2023.2192732

Theoretical framework

The seed as a system linked to the concept of a living being

The concept of life has been addressed in several publications (Coutinho, Martins, and Menezes 2011; Mortimer and El-Hani 2014). Four different approaches have been suggested to debate the living/non-living dichotomy. Three of these approaches are outside the field of scientific knowledge. The fourth, and most frequently discussed, supports the idea that most people believe that living beings come from inert matter (Barrera and López 2018).

Children understand a restricted meaning for the term 'seed' and a number of non-scientific ideas relating to the internal structure of a seed, germination and seed formation (Jewell 2002). The identification of the living being concept through the study of its vital functions is something recurrent in educational proposals from an early age. Nevertheless, it is known that learners have a generalised idea that something is alive if it moves. Due to the complexity of these concepts, viruses, bacteria, unicellular algae or seeds are usually overlooked when using living beings in working with students (Nagel 2006). It is important to emphasise the idea that learning and doing are inseparable actions. Jiménez Aleixandre (2007) emphasises the importance of adapting new concepts to ideas that already exist in the learners. To do this, the learner must be aware of the need for learning. Learners' previous experience with aspects related to what constitutes a living being should be considered as a point of reflection from which to advance in the acquiring of more complex content (Oliva 2019). However, these concepts require a greater capacity for abstraction since they are not easily observable. Undesirable learning can lead to the transfer of inappropriate attributes between humans and animals or animals and plants (Chi 2005). The meaning of animal life is intuitively constructed earlier than the meaning of plant life or any other form of life. The language used to frame or define the former will influence the construction of the others. Germination, used in the learning process, is linked to the meanings related to living beings, moral issues, resilience, being born, beginning, growing,

Therefore, it is important to show what is meant when the concepts 'seed' and 'germination' are used by science and by learners, in contrast to the lexical definition (Coutinho, Martins, and Menezes 2011). From the field of biology, the concept of life can be summarised in a single dominant process, reproduction (Sene 2011). All other processes that are carried out to achieve this, such as germination, are characteristics of living beings.

Seed and germination concepts: historical background

The germination of seeds was considered a mystery in pre-scientific cultures. An analogical symbology with birth, death and resurrection could be reflected in the observations of seed dormancy and gemination, and plants grown in agricultural activities (Evenary 1984). Various ancient authors referred to the properties of seeds of different species and also to the variables that influence their germination. A summary of their views is presented in Table 1. In the seventeenth and eighteenth centuries, analogies between plants, minerals and animals predominated (Gleichen 1799; Henckel 1760; Le Trevisan 1695). From the twentieth century, the mechanisms to produce seeds which contain genetic information allowing reproduction of plant species have been studied by researchers. Ayala (1984) proposed that the plant that grows from the seed is a different, more complex system that the seed itself in that it develops various organs that were not in the seed but already inscribed in the genetic material and these will allow the plant to perform different and much more complex functions (Cano 2009).

Germination is a life history event at the microscopic level, that affects the macroscopic level observed by learners, perhaps without a visible link (Bello 2004; Chi 2005). Lately, the contributions of the so-called 'plant cognition' researchers have suggested that despite the lack of a nervous system, plants have an intelligence capable of memorising, learning and making decisions, which facilitates their adaptation to the environment (Parise, Gagliano, and Souza 2020). These interesting

Table 1. Seed germination variables (own elaboration, from Columella 1824; Evenary 1984; Pliny II 1629; Maro 1793).

Extrinsic variables	Theophrastus (IV-III B.C.)	Virgil (I B.C.)	Columella (I A.C.)	Pliny (I A.C.)
Water (humidity)	x	x	x	x
Temperature	x	x	x	x
Year season	x	x	x	
Habitat	x	x	x	
Grain preparation		x	x	
Pairing with other species			x	
Astrology principles	x	x	x	
Intrinsic variables				
Age of the seeds	x			x
Seed weight			x	x
Spike grain quantity			x	x
Seed colour			x	x

contributions, seen from the psychology of learning, do not cease to be treated with scepticism from the perspective of biology or plant physiology and of course they are a new challenge for teaching and learning. Educational approaches are developed in more detail in the next section.

Educational approaches of germination: a review of models and didactic proposals

Biology is essentially conceptual, observational, comparative (Mayr 2006) and predictive (Gefaell 2016). Theories of evolution explain the concept of germination under certain conditions based on genetic adaptations (Acevedo-Díaz 2017). However, other aspects of germination apart from the genetic/evolutionary ones need to be explained to avoid serious difficulties in proving certain statements experimentally in order to formulate the laws of biology that govern observations and the theories that explain events (Mayr 2006). There is a great variety of thought and ways of expressing the concepts related to the cultivation of plants linked to popular knowledge which is assumed to be substantially different from scientific postulates (Halloun 2006). Starting from the model of students' ideas and the conceptual change suggested by Posner et al. (1982), other complementary models emerged. Mortimer and El-Hani (2014) suggested that the initial ideas are not replaced in the learner. On the contrary, they coexist and will be used according to the family, work or academic context in which they are to be used. To fix the different amplitudes, certainties and difficulties in the configuration of a given concept, three approaches can be used (Pedreros 2012): the history of science and epistemological analysis, previous research on alternative thinking and collected data. The concept of 'big ideas' to create science concepts is also of interest (Harlen 2015). According to Harlen, these ideas can be used to explain and make predictions about a range of related phenomena in the natural world. In that sense, seed germination allows learners to verify that seeds grow, reinforcing the idea of living and non-living. Later, it will be possible to relate it to a principle, a great idea, the unique cellular structure of living beings.

Didactic proposals to study the model and ideas of seed germination have been carried out from infant and primary education (Botero 2018; Coyoc 2010; Griset et al. 2005; Olvera and López Mota 2019) to university-level education, and have been included in the training of future teachers (Vidal and Membiela 2014). Experiments that revealed performances in tasks concerning taxonomy and flower biology including the lifecycle of flowering plants (Kissi and Dreesmann 2020) and genetics (Mulligan and Anderson 1995), were found to be of interest to students as well as teachers. These concepts were also linked to ecological literacy (Ju and Kim 2011; Vázquez, García-Rodeja, and Sesto 2020). The main variables identified by students in previous studies when working with the germination process in the classroom are summarised to represent the data shown in Table 2. Initial ideas about the events that occurred during the germination process are related to complex thinking interacting with identified variables (interpreted from Hartmann and Kester 1997; Osuna, Osuna, and Fierro 2017).

Table 2. Students´initial ideas about the events that occurred during the germination process related to complex thinking interacting with extrinsic and intrinsic variables.

Events (occurred during germination process). Initial ideas.	Complex thinking. Interactions with variables
Germination depends on the presence of water	**Extrinsic variables**
Gemination depends on temperature	Diffusion, inhibition, osmosis, permeability
Germination depends on the presence of oxygen	Temperature/temp. gap, speed (depends on the specie)
Germination does not need light	Enough oxygen is necessary for aerobic respiration, to obtain energy from respiration
Germination depends on simultaneity of requirements	It depends on the specie
Seed is died or alive	Those requirements change over time
Genetic information	**Intrinsic variables**
	Viability, longevity, latency period
	Adaptations

Variables are grouped as extrinsic or intrinsic to the germination process. Therefore, seed germination and plant growth are frequently used in classrooms for two main purposes. On the one hand, they are used to show that the meaning of living being involves vital functions and morphology, but also, and especially in teaching degrees (Maguregi 2011). In most cases, seeds of species familiar to the students (legumes, grasses) are used. Students are familiar with them because of their nutritional function. These seeds have other important characteristics: the speed at which they germinate and the high rate of success in germination. These activities allow the collection of information and subsequent discursive processes of the students (Maguregi 2011; Márquez and Pedreira 2005). The aforementioned approaches support the idea that guided activities from an early age to address the concept of germination contribute to the building of a more complete mental model of a living being. They are supposed to be also helpful for students (learners and trainees) to learn about the nature of scientific knowledge and science itself. However, most environmental variables considered in classroom experiments are those taken from agricultural knowledge.

Research aims and questions

The initial hypothesis of this study was that students do not approach seed and germination concepts from a reasoned argument. They do not understand the characteristics and differences between living and inert beings, or their different development stages and the variables influencing them. In light of this, comparative research using an inquiry approach was conducted. Experiments with the plant species *Diplotaxis erucoides*, a wild, manageable and easy to germinate plant were implemented. The research question was: What conceptions do primary school students and trainees have about seed germination? Taking into account the learning objectives of both levels of education (University of Zaragoza 2021), this study aimed to explore the initial knowledge and claims of trainee teachers and primary school students about the process of seed germination, and to explore the application of scientific activity through didactic proposals that linked science, technique, society and sustainable development with an evaluation of acquired competences.

Research design and methodology

The observation of a daily natural event becomes a scientific procedure if it is supported by scientific content and with previously determined educational objectives. It is worth underlining that, if students reveal their beliefs and tentative ideas about seed germination based on their observations, this can lead to predictions that can be tested leading to new models that represent the relationships between variables influencing seed germination (Harlen 2015). With these aims, experimental teaching activities were carried out by the implementation of scientific practices. Therefore, students were also taught about the nature of scientific knowledge and science itself.

Historical conceptions about seeds and seed germination were taken into consideration in order to find the main obstacles in students' knowledge.

Sample and procedure

A sample of 59 primary school students (three classrooms, fourth grade, nine years old) and 82 trainee teachers (third year) of an education faculty in Aragón (Spain) participated in a classroom didactic proposal over two academic years (from September 2018 to June 2020). It aimed to compare their conceptions, as well as the effectiveness of certain teaching resources and how this is reflected in students' learning. The proposal, in the context of the inquiry methodology, included the implementation of the scientific activity (Carrasquer, Ponz, and Álvarez 2018). It began with an introductory session to present the activity to students and to detect their ideas about seed and germination concepts. Later, an experimental stage was implemented, with data collection, which concluded with evaluation, hypothesis testing and presentation of results.

Didactic proposal development

The proposal with primary school students was implemented over two months. In the introductory session, a series of questions were proposed after carrying out a motivational activity about the vegetables present in the school garden and green areas of the school itself. The students worked in 15 small groups of 4–5 people. The following questions were answered in writing after discussion in the small groups:

- Is it possible to find out if these plants grow only in this place?
- How could we demonstrate what we have said?
- Which factors can influence the germination of seeds?
- When we say 'sun', do we mean light, heat or both?
- Among all the factors proposed by the groups, which two would you choose as the most important for germination?
- How would you show that the chosen factors are necessary to germinate the seeds?

Later, germination activities with the plant species *Diplotaxis erucoides* were implemented. This is a wild plant, manageable, easy to germinate, and common in the area in which the students live. The student groups assembled the germinators under the conditions established by each one of them. The variables, after consensus were: (classroom 4A) water, oxygen; (classroom 4B) water, substrate; and (classroom 4C) water, mineral salts. It was considered pertinent to add light to the variables chosen by each of the groups. They monitored the germinators and made notes and assessments for three weeks. A final discussion was held and conclusions were drawn up in student reports.

The proposal with teacher trainees was implemented over four months, in the context of a mandatory course titled 'Didactics of Biological-geological Environment' (February 2020 to May 2020). It also began with an introductory session. The students worked individually and were asked whether they had previously carried out the germination of seeds, the context in which they implemented the activity, and if they considered it convenient to carry it out in primary education from the point of view of learning scientific content. Students also answered the following questions about seed and germination concepts: Are seeds living beings?, When does the germination of a seed begin and when does it end?, Which factors can influence the germination of seeds? Later, it was proposed that seed germination activity was designed for a primary education classroom.

Results

To clarify the results obtained, two sub-sections for primary school students and trainees are presented. A comparison between them is established in the discussion section. Neither personal data nor identifiable information are included. Participant data has been anonymised without distorting results (see Ethical Approval section). Collected answers are provided as Supplementary Data Tables (Table A to Table E).

Didactic proposal with primary school students

The students provided interesting answers prior to starting the germination experiment. Collected answers are provided in Table SA supplementary online material

Regarding the question, 'Is it possible to find out if these plants grow only in this place?', 47% based their answer on tautological argumentation, 40% proposed an experiment to answer it (27% implementation of an experiment; 13% observation of the process) and 13% considered animism to answer the question ('plants grow where they want'). Summary results by group are presented in Table 3.

In answer to the question 'How could we demonstrate what we have said?', 13% proposed observing them, 13% proposed to ask someone, 13% gave a tautological argument, and 60% proposed planting the seeds. Detailed answers by 60% of students who proposed to plant the seeds are summarised in Figure 1.

Figures 2 and 3 summarise the answers given by students to the questions 'Which factors can influence the germination of seeds?' and 'Which two would you choose as the most important for germination?'.

Learners understood the meaning of environmental variables and identified both those chosen by their group and those of the others. Collected answers are provided in Table SB supplementary online material.

It is worth mentioning that primary school students used their previous daily experiences (at home, with their families) outside the educational field to answer the proposed questions. They insisted that humidity is essential for germination, not considering the intrinsic factors of the seed.

Table 3. Answers to the question 'Is it possible to find out if these plants grow only in this place?'. Summary by group.

	Tautology	To plant	To observe	Animism
Student groups (numbered from 1 to 15)	1, 2, 7, 10, 11, 14, 15	3, 4, 5, 13,	6, 8	9,12

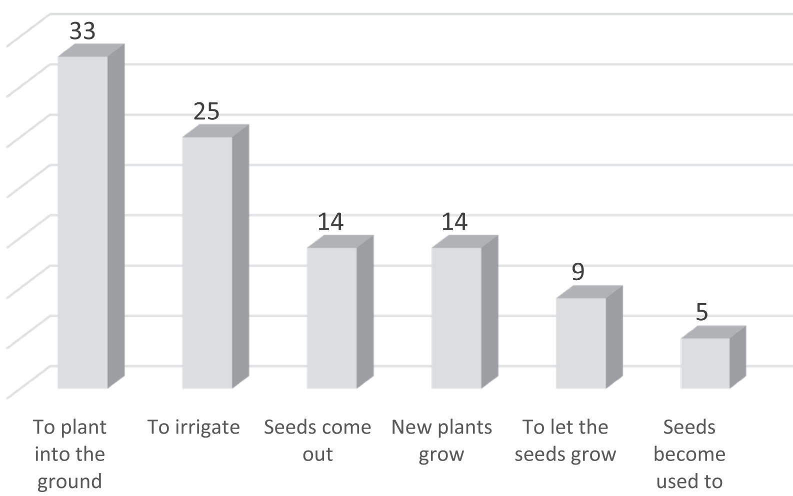

Figure 1. How could we demonstrate what we have said? (To plant the seeds, detailed answers, in %). Percent of students who chose planting the seed to demonstrate their opinion on germination needs.

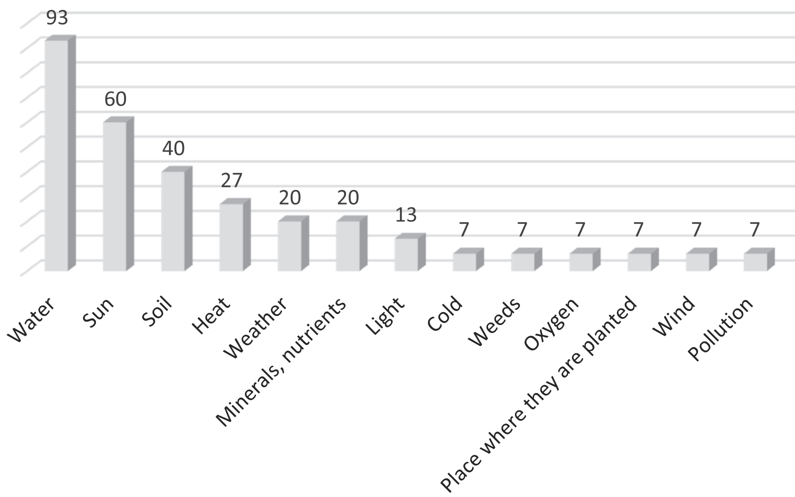

Figure 2. Which factors can influence the germination of seeds? (% of answers given by students).

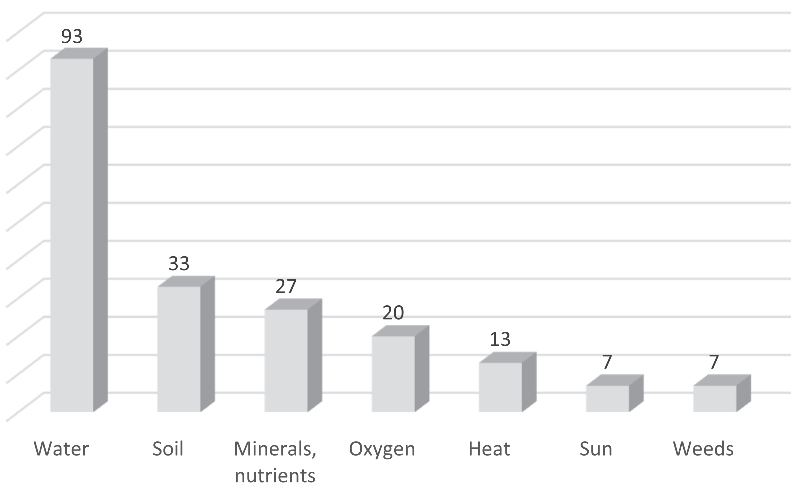

Figure 3. Which two factors would you choose as the most important for germination? (% of answers given by students).

In terms of the criteria of being alive, intrinsic factors were considered, such as those derived from genetic information or age. Non-germination was identified with the death of the seed. Another detail to take into account is the lack of relationship between the time of the year and daylight hours to explain observations. They considered that spring was the best season to germinate seeds, and to a lesser extent autumn. It should be noted that there is an orchard in the school and the students visit it.

Three aspects focused the interest of learners and therefore the discussions. The groups that chose to place seeds on moist soil and paper considered it a great surprise that they germinated on the paper, *even better than soil* and *at any time of the year*. One group was really confused when 101 seeds germinated, despite the fact that they had put 100 seeds in the germinator. Special attention was also focused on the germinators in which a vacuum had been created. A few seeds germinated, contrary to the group's prediction. The explanations were formulated with a set of opinions to justify it, ranging from light and temperature, to focusing on the existence of air inside. The group finally concluded that 'oxygen hasn't been removed well from the sides', and that it was necessary to do it again 'leaving more time for it to be done better'.

The third aspect that attracted attention was the appearance of mould in some of the germinators. It can be understood as a problem not initially contemplated. The students expressed their ideas of spontaneous generation indicating that 'it had arisen from the humidity of the water, from mineral salts, from the oxygen in the air, from bacteria or from dirt'. Some of these ideas raised doubts about their concept of a constructed living being. They were unaware of the concept of a spore, but after a brief explanation they assumed without any discussion that they are a 'species of seed', common sense learning accepted by the principle of authority.

Didactic proposal with trainee teachers

Answers given by trainees in the introductory session were also of interest. Collected answers are provided in Table SC supplementary online material.

Almost all (99%) of the students indicated that they had carried out the germination of seeds of different vegetable species before. The species are summarised in Figure 4.

Germination activities were carried out by most trainees at an early age. The contexts in which students implemented these activities were mainly schools (90%), homes (68%; 34% in family vegetable gardens), and 2% in the framework of non-formal didactic activities. The previous experience of trainees in germination is summarised in Table 4.

All the students considered it convenient to carry out these activities at an early age. The interests of trainees are shown in Table 5. Collected answers are provided in Table SD supplementary online material.

Regarding answers to the questions about seed and germination concepts, 48% agreed that seeds become living beings, 46% thought that seeds are living beings (because they perform vital functions, 39%; because they are composed of cells, 7%), 11% agreed that seeds do not perform vital functions, 15% considered them as a means of vegetable reproduction. A summary of the

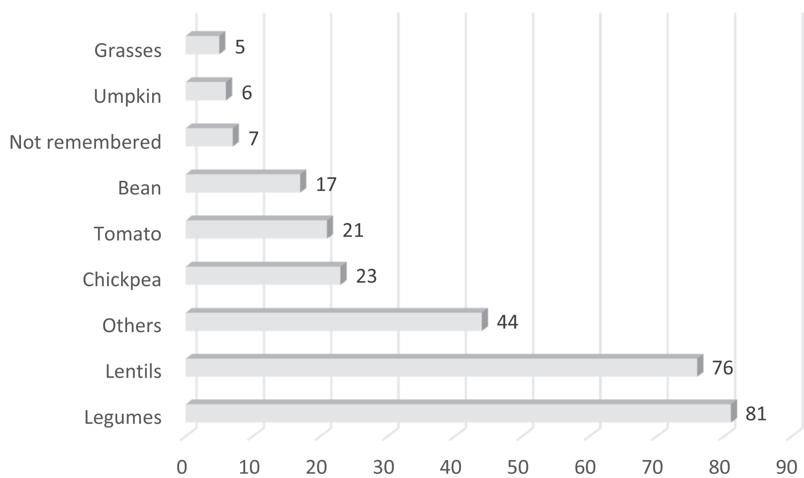

Figure 4. Seeds of plant species already used by students (% of answers given by students).

Table 4. Previous experience of trainees in germination activities.

Educational Stage	% of students
Infant and primary education (school)	90%
High school	11%
University	15%

Table 5. Interests for trainees as future teachers.

Interests of trainees	% of students
To observe germination phases	82%
To study the life cycle and growth of vegetables	68%
To learn by experimental activities	55%
Motivating pupils	35%
Promoting responsibility and environmental respect	24%
To evaluate variables	21%
Applying scientific activity	9%

Table 6. Trainees opinion on germination process.

Germination starts	% of students
Adequate environment	39%
Contact with water	32%
Appearing roots	16%
Nutrition function starts	13%
Vegetable growth	8%
When seeds are delivered by plants	4%
Germination ends	
When primary leaves appear	33%
Vegetable growth	23%
Appearing roots	12%
Flowers/fruits/seeds are produced	10%
With death	10%
Unknown	12%

answers given to the question 'When does the germination of a seed begin and when does it end?' are presented in Table 6. Regarding the variables that influence germination, 73% considered water/humidity, 54% considered light/sun, 51% considered temperature, 38% considered environmental variables (without specifying them), 22% considered soil as physical support, 21% considered oxygen/air, 17% considered nutrients, 11% considered seed characteristics and 6% considered the presence of carbon dioxide. Collected answers are provided in Table SE supplementary online material.

Finally, it was proposed that they design a seed germination activity for primary education students. Most of the students (78%) agreed to carry out a classroom activity of germination. The study of variables was considered by 18% of students, 15% proposed a garden, 6% emphasised the importance of plant development observation, and only 4% considered the formulation of a hypothesis.

Discussion

Trainee teachers and primary school students changed their assumptions about the germination process of seeds and developed their knowledge. The results outlined above show that the trainees considered the seed germination study to be an effective activity for primary school classrooms (Table 5). This involved analysing the phases of germination, the complete growth cycle of the plant and the influence of variables. According to the trainees, the methodology encouraged work and responsibility as well as promoted a scientific approach, fostering the learners' literacy surrounding the nature of scientific knowledge and science itself (Acevedo-Díaz, García Carmona, and Aragón-Méndez 2017). The results obtained by applying it in the classroom confirmed these opinions.

The approach and reasoning degree of both elementary students and trainee teachers were similar. Overall, the didactic proposal helped students to improve their knowledge about seed germination. Nevertheless, the results also showed common errors in the students' methodological approaches. Experiments related to the germination or reproduction of plants are frequently carried out in class and outside school (Table 4). According to the data collected, the seeds most used by trainees were legumes and, to a lesser extent, grasses, both of which have high germination success rates and negative phototropism (Figure 4). Therefore, observations and results may lead to misguided generalisations (Griset et al. 2005) informing inconsistent models. It is important to avoid inaccurate generalisations that focus on environmental factors (temperature, light) whose influence on germination depends on the seed's characteristics. In some cases, such as with smaller-sized seeds, evolutionary adaptations mean that a certain amount of light may be an intrinsic requirement for germination and therefore fewer nutritional reserves are required to emerge from the soil. The need for oxygen in germination is not usually considered in schools, perhaps due to the difficulties in investigating it experimentally with the necessary technical means that exist. In the activity carried out with the group of fourth grade primary education students, these difficulties, far from being an inconvenience, were translated into a reason for discussion and reflection on the part of the students. They concluded that the practice of creating a vacuum had been carried out incorrectly. However, it is also necessary to consider whether the absence of air available for the seed may be due to the presence of an excessive amount of water.

The initial hypothesis of this study was confirmed. Before the didactic proposal implementation, the students did not fully approach seed and germination concepts with a reasoned argument (Jewell 2002). Neither trainees nor learners fully understand the characteristics and differences between living and inert beings or their development stages and the variables that influence them (Figures 2 and 3, Table 6). Most of the students suggested humidity, temperature and light as the main variables that influence germination (Vidal and Membiela 2014). This is supported by the fact that 22% of the subjects considered the influence of the substrate and 17% considered the influence of nutrients in the substrate, while 6% considered the need for carbon dioxide. The placement of the seed, which can be interpreted as a factor intrinsic to it, was mentioned by 11% of the participants. A small number of students considered respiration (17% mentioned oxygen and 4% mentioned air); 13% of students explained their vitalist ideas and the problems when interpreting what the vital functions are, resulting in half of the students using these ideas to affirm that vegetables are living beings (39%) or that they are not alive (11%). The concept of spontaneous generation could be implicit in the statement that seeds are not living beings but become so (48%); 2% of students agreed with the ambiguous statement that seeds are a means of reproduction and could be interpreted as an organ of the plant. Only 7% of trainee teachers linked life with cell theory.

Conclusions

The research question set out at the beginning of this study was answered by means of the reasoning already expounded. Many of the students (both trainees and learners) are capable of generating knowledge by reasoning or making predictions, and they are capable of developing an experimental corroboration. However, when they have to solve applied problems, a domain of ingenuity is revealed (Halloun 2006). They attribute physical properties to imagined objects, and their thinking is focused more on objects than on processes.

When comparing how the elementary students reasoned vs. how the trainee teachers reasoned about the experiment and in response to the results they obtained, both groups had a similar approach. The results confirmed that the concept that seeds are associated with human nutrition interferes with the students' models. It is worth mentioning that the environmental variables typical of common knowledge or historical agricultural knowledge are those studied in the classroom, except for light, which is not present in historical ideas (Hannay 1967; Márquez and Pedreira 2005). The concept of sun is generally used by students to refer to light and heat. An excess of humidity is not related to a possible lack of oxygen. Other interesting variables derived from genetic information (Delpech 2000; Osuna, Osuna, and Fierro 2017) were not considered by either the prospective teachers or the primary education students. Finally, the differentiation of the germination process from the plant grown was hard for students to understand. The concept of cellular respiration is more inclusive than that of photosynthesis, but students seem to link both.

We conclude that these results can be used in improving future teachers' training for elementary school teaching. It is necessary to give greater attention to practical classroom activities that facilitate the construction of models based on concepts, theories or principles distinct from common or historical agricultural knowledge (Mayr 2006) in the preparation of the trainees. For example, variables derived from genetic information (size of the seed, latency period) are significant and helpful in developing a more reasoned learning approach. It is also considered essential to work on the meaning and proper use of scientific terms, such as living and inert matter, sexual and asexual reproduction, sun-light-heat, or plant germination and growth processes. It would also have been helpful to stress the importance of the concept of dormancy and to find inhibitors (Lenz 1993) and other possible factors that prevent the seeds from germinating such as pathogens, low temperatures, adaptation or the presence of chemical substances (Horsley 1990; Whiteley et al. 2003).

It is also of relevance to provide tools and promote full understanding of the seed model in trainee teachers. To reach this, function and conferred structures of a seed and an egg can be used since they are similar. Inside a seed's envelope, the cotyledons, vegetable equivalents of the albumen and the yolk of the egg, constitute the nutritional reserve. Nevertheless, a first and great difference is manifested in the behaviour of the embryo. The plant embryo development is not continuous until birth; it starts to grow shortly after fertilisation, and then it stops. This pause can go on for a long time (months, years) before favourable conditions for germination are forthcoming. Therefore, discussing dormancy is important in order to understand what those conditions are and how they change depending on the plant species. However, initially, it is necessary for students to understand that the seed has to reach a favourable place for its germination and the consequent establishment of new individuals by dispersal. Examples can be proposed: blowing on a dandelion, or with the help of the wind or insects. In this respect, the idea of capturing the students' imagination by having them pretend that they are a seed is fantastic. It encourages students to 'empathise', or put themselves in the place of a seed, and to understand and identify how intrinsic and extrinsic factors influence how they carry out their vital functions.

Rapid germination with a high success rate should not be considered as a benchmark of a successful didactic activity. The non-germination of a seed, or its delay in doing so (multi-causality, complexity), is not a failure, but rather it generates an uncertainty typical of scientific research. Seeds are a complex stage of a living being and they do not need to germinate to be considered as such, so it is important that the learner grasps the concept of a seed bank (Ju and Kim 2011) to understand the complexity of the environment and the environmental importance of the perpetuation of vegetable species in it.

Acknowledgments

The authors would like to thank students and colleges who made possible the collection of data to carry out the study and also to the Beagle research group (S27_20R) and the IUCA Research Institute, both of the University of Zaragoza. The authors thank to the reviewers all suggestions which significantly increase the quality of the manuscript.

Informed consent

Informed consent under no coercion or bribery of any kind, in accordance with the principles outlined in the Nuremberg Code and the Belmont Report, has been obtained from the participants or from the parent or guardian of any participants who are not able to provide full informed consent themselves.

Disclosure statement

Authors confirm that there are no financial or non-financial competing interests to report.

Funding

This work was supported by the Projects PID2019-105320RB-I00 financed by MCIN/AEI/10.13039/501100011033; MINECO EDU2016-76743-P project; CIENCIATE3-2018/B001; CIENCIATE4-2020-B002; PIIDUZ_19_525 and PIIDUZ_1_21_231.

ORCID

Beatriz Carrasquer-Álvarez http://orcid.org/0000-0001-9336-4644
Adrián Ponz-Miranda http://orcid.org/0000-0003-4147-1821

Ethical approval

The study was undertaken in accordance with the UNESCO Declaration on Science and the use of Scientific Knowledge, the University of Zaragoza Good Practice Guidelines, and the British Educational Research Association's Ethical Guidelines for Educational Research. Confidential and anonymous treatment of participants' data has been considered for the conduct of research. Neither personal data nor identifiable information are included. Participants´ data have been anonymised without distorting results. Researchers engaged with participants at the conclusion of the research by eliciting feedback on the findings. Researchers´ contact details and information about the characteristics and proposals of the study were provided to participants. Informed consent details are included next.

References

Acevedo-Díaz, J. A. 2017. *Sobre Leyes Y Teorías Científicas [On Scientific Laws and Theories]*. Iberoamérica divulga. doi:10.13140/RG.2.2.29995.64804/1.

Acevedo-Díaz, J. A., A. García Carmona, and M. M. Aragón-Méndez. 2017. "*Enseñar Y Aprender Sobre la Naturaleza de la Ciencia Mediante el Análisis de Controversias de Historia de la Ciencia. Resultados Y Conclusiones de Un Proyecto de Investigación Didáctica* [Teaching and Learning About the Nature of Science Through the Analysis of Controversies in the History of Science. Results and Conclusions of a Didactic Research Project]." *Organización de estados Iberoamericanos para la Educación, la Ciencia y la Cultura* 1: 1–165.

Ayala, F. J. 1984. "Relaciones Ontológicas Metodológicas Y Epistemológicas Entre la biología Y la Física [Methodological and Epistemological Ontological Relations Between Biology and Physics]." *Contextos* 2 (3): 7–20.

Bachellard, G. 2000. "La Formación del Espíritu Científico. Contribución a un Psicoanálisis del conocimiento Objetivo." In *[The Formation of the Scientific Spirit. Contribution to a Psychoanalysis of Knowledge Objective]*, edited by España, 23rd ed., 1–302. Madrid: Siglo XXI.

Barrera, A., and M. J. López. 2018. "¿existe Una Frontera Nítida Entre Lo Vivo Y Lo Inerte? [Does a Clear Limit Between the Living and the Inert Exist?]." *Revista de Bioética y Derecho, Perspectivas Bioéticas* 43: 9–31.

Bello, S. 2004. "Ideas Previas Y Cambio Conceptual [Previous Ideas and Conceptual Change]." *Educación Química* 15 (3): 210–217. doi:10.22201/fq.18708404e.2004.3.66178.

Botero, M. 2018. *Papel de la regulación metacognitiva en el aprendizaje del concepto de germinación en estudiantes de grado séptimo* [Role of metacognitive regulation in learning the concept of germination in seventh grade students]. [Master´s Thesis]. Manizales, Colombia, Universidad Autónoma de Manizales.

Cano, D. 2009. "Teleología en el pensamiento biofilosófico de F." *Journal Ayala [Teleology in Biophilosophical Thought] Pensamiento* 65 (246): 915–948.

Carrasquer, B., A. Ponz, and M. V. Álvarez. 2018. "Germinación de semillas en Educación Primaria [Germination of seeds in Primary Education." In *Avances en Ciencias de la Educación y del Desarrollo*, edited by Asociación Española de Psicología Conductual, 882–888. Granada: Universidad de Granada.

Chaves, G. A. 2016. "La enseñanza y el aprendizaje de la evolución biológica (EB) con la perspectiva teórica del perfil conceptual: Implicaciones en la formación continua del profesorado [The teaching and learning of biological evolution (BE) with the theoretical perspective of the conceptual profile: Implications in the continuous training of teachers]." *Biografía Escritos sobre la Biología y su enseñanza* 9 (17): 109–117.

Cherubini, M., H. Gash, and T. McCloughlin. 2008. "The DigitalSeed: An Interactive Toy for Investigating Plants." *Journal of Biological Education* 42 (3): 123–129. doi:10.1080/00219266.2008.9656125.

Chi, M. T. H. 2005. "Commonsense Conceptions of Emergent Processes: Why Some Misconceptions are Robust." *Journal of the Learning Sciences* 14 (2): 161–199. doi:10.1207/s15327809jls1402_1.
Columella, L. J. M. 1824. *Los doce libros de agricultura [The twelve books of agriculture] (vol. 1), traducidos al castellano por Juan María Álvarez de Sotomayor y Rubio*. Madrid: Miguel de Burgos.
Coutinho, F. A., R. Martins, and J. Menezes. 2011. "Abordaje relacional al concepto biológico de vida y sus implicaciones éticas y jurídicas [Relational approach to the biological concept of life and its ethical and legal implications]." *Prometeica, Revista de Filosofía y Ciencias* 1 (3): 20–44. doi:10.24316/prometeica.v0i3.58.
Coyoc, R. N. 2010. *Las Ciencias Naturales en Primer Grado de Educación Primaria, las Plantas* [Natural Sciences in First Grade of Primary Education, Plants]. [Innovación Project, Educación degree]. México: Universidad Pedagógica Nacional de México. http://200.23.113.51/pdf/27002.pdf
Delpech, R. 2000. "Investigating the Phenomenon of Programmed Cell Death in Maize (*Zea mais*) Seeds." *Journal of Biological Education* 35 (1): 41–44. doi:10.1080/00219266.2000.9655734.
Evenary, M. 1984. "Seed Physiology: Its History from Antiquity to the Beginning of the 20th Century." *The Botanical Review* 50 (2): 119–142. doi:10.1007/BF02861090.
Gayon, J. 2010. "Defining Life: Synthesis and Conclusions." *Origins of Life and Evolution of Biospheres* 40: 231–244. doi:10.1007/s11084-010-9204-3.
Gefaell, J. 2016. "Ernst Mayr: Una filosofía desde la Biología, una Biología desde la Filosofía. Brevísimo repaso a sus aportaciones. [Ernst Mayr: A philosophy from Biology, a Biology from Philosophy. Very brief review of his contributions]." *Revista de Bioloxía* 8: 178–188.
Gleichen, W. F. 1799. *Dissertation sur la génération, les animalcules spermatiques, et ceux d'infusions, avec des observations microscopiques sur le sperme, et sur différentes infusions. [Dissertation on generation, spermatic animalcules, and those of infusions, with microscopic observations on sperm, and on different infusions]*. Paris: L ´Imprimirie de Digeon.
Griset, E., M. Pedreira, O. Schaaff, and R. M. Tarín. 2005. "Diferents Entorns D'aprenentatge per Treballar el Model D'ésser Viu a l'educació Infantil I Primària [Different Learning Environments to Work on the Model of Being Alive in Early Childhood and Primary Education]." *Enseñanza de las Ciencias* Extra VII: 1–5.
Halloun, I. A. 2006. *Modeling Theory in Science Education*. Dordrecht: Springer.
Hammann, M., T. T. Hol Phan, M. Ehmer, and T. Grimm. 2008. "Assessing pupils' Skills in Experimentation." *Journal of Biological Education* 42 (2): 66–72. doi:10.1080/00219266.2008.9656113.
Hannay, J. W. 1967. "Light and Seed Germination-An Experimental Approach to Photobiology." *Journal of Biological Education* 1 (1): 65–73. doi:10.1080/00219266.1967.9653461.
Harlen, W., edited by. 2015. *Trabajando con las Grandes Ideas de la Educación en Ciencias [Working with the Big Ideas of Science Education]*. Triste: IAP.
Hartmann, H. T., and D. E. Kester. 1997. In *Propagación de plantas. Principios y prácticas*, 5ªth ed. México: Compañía Editorial Continental, S.A.de C.V. Plant propagation 5ª
Henckel, J. F. 1760. *Flora Saturnisans, ou preuves de l'alliance qui existe entre le Regne Végétal, et le Regne Minéral [Flora Saturnisans, or forecasts of the alliance that exists between the Regne Végétal, and the Regne Minéral] en Jean Frederic Henckel, Oeuvres de M. Henckel*. París: Jean Thomas Hérissant.
Horsley, A. 1990. "Acid Rain in the Laboratory: An Investigation into the Effects of Sulphur Dioxide Gas on Wheat Seed Germination." *Journal of Biological Education* 24 (2): 71. doi:10.1080/00219266.1990.9655108.
Jewell, N. 2002. "Examining Children's Models of Seed." *Journal of Biological Education* 36 (3): 116–122. doi:10.1080/00219266.2002.9655816.
Jiménez Aleixandre, M. P. (Coord.). 2007. *Enseñar ciencias [To teach sciences]*. Barcelona: Editorial Graó.
Ju, E. J., and J. G. Kim. 2011. "Using Soil Seed Banks for Ecological Education in Primary School." *Journal of Biological Education* 45 (2): 93–101. doi:10.1080/00219266.2010.546010.
Kissi, L., and D. Dreesmann. 2020. "Flowers with Powers – Conception and Evaluation of an 'Educational Seed mix'." *Journal of Biological Education* 56 (2): 147–162. doi:10.1080/00219266.2020.1757485.
Lenz, P. 1993. "Inhibition of Mustard Seed Germination by *Calluna* Extract." *Journal of Biological Education* 27 (2): 87–89. doi:10.1080/00219266.1993.9655310.
Le Trevisan, B. 1695. *Le texte D'Alchymie, et le Songe-Verd [The alchemy text]*. Laurent D'Houry.
Maguregi, G. 2011. "Las semillas no necesitan luz para germinar.[Seeds do not need light to germinate." In *XXV Encuentro de Didáctica de las Ciencias*, edited by J. M. Domínguez Castiñeiras, 465–471, Santiago de Compostela: Universidade de Santiago de Compostela y APICE.
Maro, P. V. 1793. "Las Eclogas y Georgicas de Virgilio, Rimas y el Pompeyo, Tragedia." In *[The Eclogues and Georgics of Virgil, Rhymes and Pompey, Tragedy]*, edited by Christoval de Mesa, 1–346. Madrid: Ramón Ruiz.
Márquez, C., and M. Pedreira. 2005. "Dialogar sobre lo esencial: una propuesta de trabajo en clase de ciencias [Dialogue about the essentials: a work proposal in science class]." *Alambique* 44: 105–112.
Mayr, E. 2006. *Por qué es única la biología. Consideraciones sobre la autonomía de una disciplina científica [Why is biology unique? Considerations on the autonomy of a scientific discipline]*. Buenos Aires: Katz Editores.
McEwen, B. 2007. "Easy Growth Experiment on Peas Stimulates Interest in Biology for 10–11 Year Old Pupils." *Journal of Biological Education* 41 (2): 84–88. doi:10.1080/00219266.2007.9656068.

Mortimer, E., and C. El-Hani, edited by. 2014. *Conceptual Profiles a Theory of Teaching and Learning Scientific Concepts*. USA: Springer.
Mulligan, B., and M. Anderson. 1995. "*Arabidopsis thaliana*: A Versatile Plant for Teaching and Research Projects in Genetics and Plant Biology." *Journal of Biological Education* 29 (4): 259–269. doi:10.1080/00219266.1995.9655459.
Nagel, E. 2006. *La estructura de la ciencia. Problemas de la lógica de la investigación científica [The structure of science. Problems of the logic of scientific research]*. Buenos Aire: Paidós.
Oliva, J. M. 2019. "Distintas acepciones para la idea de modelización en la enseñanza de las ciencias [Different meanings for the idea of modelling in science teaching]." *Enseñanza de las Ciencias* 37 (2): 5–24. doi:10.5565/rev/ensciencias.2648.
Olvera, M. T., and A. D. López Mota. 2019. "*Evaluación del logro del modelo científico escolar de arribo sobre germinación por estudiantes de biología mediante una secuencia didáctica* [Evaluation of the achievement of the arrival school scientific model on germination by biology students through a didactic sequence ." In *La investigación y la intervención en el posgrado UPN*, edited by Coordinación de posgrad, 113–130. Bogotá: Universidad Pedagógica Nacional.
Osuna, H. R., A. M. Osuna, and A. Fierro. 2017. *Manual de propagación de plantas superiores [Higher Plant Propagation Manual]. Universidad Nacional Autónoma de México*. México: Universidad Autónoma Metropoliana.
Parise, A. G., M. Gagliano, and G. M. Souza. 2020. "Extended Cognition in Plants: Is It Possible?" *Plant Signalling & Behavior* 15 (2): 1710661. doi:10.1080/15592324.2019.1710661.
Pedreros, R. I. 2012. "Dimensión del perfil conceptual en las investigaciones sobre enseñanza de las Ciencias [Conceptual profile dimension in science teaching research], en Adelaida Molina (Comp.) ." In *Énfasis, Perpectivas Epistemológicas, Culturales y Didácticas en Educación en Ciencias y la Formación de Profesores: Avances de Investigación*, edited by Fondo de Publicaciones Universidad Distrital Francisco José De Caldas, 111–148. Bogotá: Universidad Distrital Francisco José de Caldas.
Pliny II, C., II. 1629. "*Historia Natural de Cayo Plinio Segundo, Traduzida por el Licenciado Geronimo de Huerta, Medico de su Magestad, y Familiar del sanmto Oficio de la Inquisición* [Natural History of Cayo Plinio Segundo." In *Physician to His Majesty, and Relative of the Holy Office of the Inquisition]. Tomo Segundo*, edited by G. de Huerta. Madrid: Juan Gonçalez.
Posner, G. J., K. A. Strike, P. W. Hewson, and W. A. Gertzog. 1982. "Accommodation of a Scientific Conception: Toward a Theory of Conceptual Change." *Science Education* 66 (2): 211–227. doi:10.1002/sce.3730660207.
Sene, F. M. 2011. "La vida al natural y la intervención de la vida [Natural life and intervention of live]." *Prometeica* 1 (3): 6–19. doi:10.24316/prometeica.v0i3.57.
University of Zaragoza 2021. Curriculum of Education Degrees. Available at: https://educacion.unizar.es/grado-primaria/grado-en-magisterio-en-educacion-primaria (accessed 19 November, 2021).
Vázquez, C., I. García-Rodeja, and V. Sesto. 2020. "Modelos del alumnado de Primaria sobre las semillas desde la perspectiva de eco-alfabetización [Models of Primary students about seeds from the perspective of eco-literacy]." *Innovación Educativa* 30 (30): 95–111. doi:10.15304/ie.30.7063.
Vidal, M., and P. Membiela. 2014. "On Teaching the Scientific Complexity of Germination: A Study with Prospective Elementary Teachers." *Journal of Biological Education* 48 (1): 34–39. doi:10.1080/00219266.2013.823881.
Whiteley, L., J. Gibbon, J. Hofgartner, C. Mason, and H. Willmetts. 2003. "The Effects of Different Concentrations of Lead Salts on a Variety of Crop Plants." *Journal of Biological Education* 37 (4): 190 195. doi:10.1080/00219266.2003.9655882.