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Students' conceptions of plant reproduction processes This paper was presented at the ERIDOB conference 2020

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ABSTRACT

Understanding plant reproduction is an important goal in biology education. Unfortunately, various studies show that students have difficulties in connecting the stages of plant reproduction. Students' conceptions of the processes of sexual reproduction (e.g. pollination and seed dispersal) remain unclear, although these conceptions appear crucial for understanding plant reproduction. Therefore, the current study focuses particularly on students' conceptions of the processes of plant reproduction. To assess students' conceptions, we used open-ended tasks and analysed the answers through qualitative content analysis. In this contribution we present the results of the task 'Open description of plant reproduction', which asked students to draw and describe their ideas of plant reproduction. The task was completed by 228 Austrian students from secondary school (age 10–18). The results show that students often describe only one of the processes involved in reproduction (either pollination or seed dispersal) but rarely describe the correct consecutive order of both processes. Moreover, many students from all age groups mix pollination and seed dispersal. This implies that it is necessary to address the confusion of these processes explicitly. The presented task can further help to easily assess students' conceptions in class and specifically address students' difficulties and needs.

KEYWORDS
Students' conceptions; plant reproduction; conceptual change; pollination; plant blindness

Introduction & theoretical background

The topic of plant reproduction provides the basis for comprehending the most striking features of flowering plants: flowers and fruits. The qualities of flowers and fruits (colour, shape, scent, edibility) are important criteria for building concepts of plants (Tunnicliffe 2001; Bartoszeck et al. 2015). Moreover, the high signal value of flowers can draw attention to plants and counteract the phenomenon of plant blindness (Wandersee and Schussler 2001). Plant blindness describes the problem that plants and their importance for our daily lives are often overlooked (Wandersee and Schussler 2001) which is problematic due to their major role as primary producers of organic compounds in nearly all ecosystems (Clary and Wandersee 2011) and as the basis for human nutrition (Klein et al. 2007). Hence, understanding plant reproduction provides insight into the life of plants and helps to realise important environmental problems. For instance, students can understand the possible effects of the current decline of honeybees and other insects (Evans et al. 2009; Hallmann et al. 2017) only in combination with plant reproduction.

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Understanding the reproduction of plants is therefore an important goal in biology education (National Research Council 2012). In this contribution, we focus on the life cycle of flowering plants including the consecutive sequence of the processes of sexual reproduction, namely pollination, pollen tube growth, fertilisation, seed development and seed dispersal. An understanding of these processes is crucial to comprehensively understand how plants reproduce in natural and in agricultural contexts. Additionally, plant reproduction offers many possibilities for easily applicable experiments at school (Heß 1990) and to observe movements in plants (Lord and Russell 2002; Willmer 2011). Moreover, the topic illustrates how botany connects to other fields of biology such as zoology, ethology and evolution, particularly in the context of pollination and seed dispersal (Willmer 2011). All these issues indicate that plant reproduction should serve as a fruitful topic in biology education.

However, several studies show that understanding plant reproduction proves difficult. Since we perceive learning as a constructive process in which students build up their knowledge based on the information received and their prior conceptions (Gerstenmaier and Mandl 1995), it requires the investigation of students' conceptions to evaluate their starting points of learning (Riemeier 2007) or their learning pathways. 'Learning', in this context, is defined as a 'change' or rather as an ongoing 'reconstruction' of conceptions, which is described by the Conceptual Change-Theory (Strike and Posner 1992; Duit and Treagust 2003; Krüger 2007).

Which conceptions of plant reproduction have to be considered? Helldén (2000) showed that students have difficulties in understanding the role of the flower. In addition, the author mentions students' difficulties in differentiating between pollination and seed dispersal which was also addressed in other studies (Boyer 2000; Nyberg, Andersson, and Leach 2005). Jewell (2002) explored students' conceptions of seeds and showed that students struggle particularly to explain how seeds originate. Nyberg, Andersson, and Leach (2005) and Schussler and Winslow (2007) demonstrated that the connection between flowers and fruits is often unclear. Benkowitz and Lehnert (2010) provided information that students have difficulties in understanding plant reproduction as a cycle, which was also supported by Quinte (2016).

These investigations mainly focused on the observable stages of plants but not on students' conceptions of the underlying processes of sexual reproduction. The observed difficulties in connecting the stages can only be explained when we have knowledge about students' own ideas of the involved processes. Therefore, in the current study we focus on students' conceptions of these processes and address the following questions in this article:

- Which processes do secondary school students associate with plant reproduction?
- How do students relate these processes to each other?

Materials and methods

Design of the study

We investigated students' conceptions of plant reproduction using a multi method approach, which included semi-structured interviews in a pre-study and open-ended writing tasks in the main study. The interviews of the pre-study were conducted with seven students from 5^{th} grade (age 10–11) and focused on students' conceptions of pollination (Lampert 2012; Lampert et al. 2018).

To get a more comprehensive picture of students' conceptions of plant reproduction, we broadened our field of investigation in the main study in three ways: We covered a broader range of age groups, included a larger number of students, and widened the scope to conceptions of plant reproduction in general. For these purposes, we designed open-ended writing tasks. The preliminary tasks were tested with four students using think-aloud protocols (Konrad 2010), and further tested in five classes to see how students responded to the tasks. Three open-ended writing tasks were selected after this testing phase (Lampert et al. 2019).

In the present article, we focus on only one of these tasks; 'Open description of plant reproduction'. This task is based on the approach of Schussler and Winslow (2007) who investigated students' ideas about plant reproduction. In their study, students were encouraged to think of other life cycles (e.g. of butterflies) and to use this knowledge to draw a life cycle of a plant (*Brassica rapa*) starting with a seed. This approach provides an easy way to assess how students imagine the life cycle of a plant including plant reproduction. However, the authors mentioned difficulties in analysing the drawings, because written explanations were often missing. Another critical aspect of their task is that students' conceptions might be influenced by the given 'clues' (comparison with other life cycles; using *Brassica rapa* as an example; seed as a starting point).

Taking advantages and disadvantages of the task of Schussler and Winslow (2007) into account, we created a task which requires both drawings and written explanations. The task consists of a statement introducing the phenomenon of plant reproduction ('Plants manage to reproduce and spread although they are usually fixed in the soil') which is followed by a question about students' ideas ('How do you imagine the reproduction and spreading of plants?'). Finally, the students are encouraged to make a drawing including captions first and then to explain their ideas in words (see the full task in the appendix). Combining drawing and writing should make analyses easier and help children who have difficulties in writing or drawing. The task does not include any information about a specific plant and does not give input about specific structures such as seeds or pollen. This allows students to express their own ideas and use their own images and words without influence from specific terms or examples.

Data collection and analysis

In the main study, we assessed 724 students (all three tasks) from 5th to 12th grade (age 10–18) in four different federal states of Austria including 32 classes from eight schools. The sampling comprised at least four classes from each grade. Only the 11th grade was excluded because in Austria most schools do not teach biology in 11th grade. Only one of the three tasks was assigned randomly to each student leading to 228 completed 'Open descriptions of plant reproduction'. The students had 20 minutes to complete the task. We did not collect any further data from the students.

To get a complete record of students' answers including their drawings, all documents were scanned. In addition, all written answers were typed to facilitate the qualitative content analysis (Mayring 2008; Kuckartz 2014) which was conducted with MAXQDA 18 (MAXQDA 2018). Based on the previous studies (Lampert 2012) and the material itself, we created a coding guideline consisting of eight codes (see results). The guideline included descriptions and characteristic examples for each code.

Each document was coded with only one of these eight codes. The only exception was the code 'alternative way of reproduction' which was assigned in addition to other codes in 14 cases. The complete dataset (n = 228) was coded independently by two researchers who agreed initially in 86.8% (198 documents) of all cases. The 30 documents which were coded differently in the first place were discussed and assigned to one code in a consensual discussion. This procedure not only improved reliability of the results but also showed that the coding system is easily applicable and reflects students' conceptions well.

Results

We first present the eight codes and then provide an overview of the whole population studied. Since the assessment task was formulated in an open way, a complete biological explanation could include all processes of a life cycle of flowering plants, describe vegetative reproduction or treat reproduction mechanisms of other plant groups (ferns, mosses, etc.). We inferred from their descriptions and drawings that most students (>95%) described and drew reproduction of flowers or trees. This indicates that students mainly thought of flowering plants when they read 'plants'. Therefore, we refer to flowering plants when we use the word 'plant'.

Types of students' conceptions

We focused in our analyses mainly on the two observable processes of pollination and seed dispersal, which are most relevant to explain the statement in the task ('Plants manage to reproduce and spread although they are usually fixed in the soil'). Since we assigned only one code to each document, the codes reflect types of students' conceptions. These types are defined below, including typical examples to illustrate each type and inherent variations.

(1) **Students give an unclear answer or answer is missing ('Unclear/Missing')**

The spectrum of answers reaches from students who did not write anything to written statements that were not interpretable. Only six students did not give any description, which indicates that the task was comprehensible for most students. The following examples illustrate answers which were not clear enough to be assigned to another type:

> Bees play an important role in plant reproduction; so does the weather. [IB_4_20]

> Plants reproduce by means of pollen. [Drawing in Appendix 2] [NQ_1_16]

(2) **Students describe only growth of the plant ('Growth only')**

Answers of this type do not describe sexual processes but only describe the growth of a plant.

> The plant takes up nutrients via rain and light and grows. [...] Light is needed by the plant for photosynthesis. [Drawing in Appendix 2] [BQ_5_15]

> The plant develops from a small seed to a big plant. [LX_2_20].

(3) **Students describe an alternative means of reproduction ('Alternative way')**

This type includes very diverse answers because students described a broad variety of possible alternative ways of reproduction, not all in line with factual ways. 15 students described only alternative ways of reproduction, whereas 14 students described an alternative way in addition to another (sexual) means of reproduction. One typical subtype refers to asexual reproduction via runners or roots. Another typical subtype contains answers, where other substances than pollen or seeds are transferred (e.g. spores, nectar, the flower itself). The remaining alternative answers describe incorrect concepts such as reproduction via photosynthesis or other alternative ways.

> 1. A plant develops spores which are dispersed by wind. 2. Strawberries can develop offshoots that grow from the soil. [...] [NQ_6B_20]

> Plants reproduce via photosynthesis; they do not need a partner [Drawing in Appendix 2] [BQ_6_18]

(4) **Students describe only pollination ('Pollination only')**

Typical answers of this type only describe the process of pollination but do not write about seed dispersal. The answers are correct but incomplete descriptions of plant reproduction.

> Sun and rain nourish the plant. When a bee comes and wants nectar from the plant, a pollen grain sticks on its body. When the bee flies to another plant, the pollen grain slips into the plant and fertilises the plant. THE END! [Drawing in Appendix 2] [IB_2B_22]

(5) **Students describe only seed dispersal ('Seeds only')**

This type includes answers describing seeds or fruits which are dispersed but do not refer to pollination, which leads to correct but incomplete descriptions of plant reproduction. Some students even describe a life cycle of a plant, but without mentioning pollination or fertilisation.

> The wind takes away the seeds and where they fall on the ground they can grow and develop to new plants. [Drawing in Appendix 2] [BQ_2_17]

(6) **Students mix pollination and seed dispersal ('Pollen X Seeds')**

This type contains answers that do not clearly differentiate the processes of pollination and seed dispersal but mix these. Three ways of mixing are possible in this context. First, students describe seeds which are transferred to a flower instead of pollen. Second, they describe pollen which lands on the ground and leads to the growth of a new plant. Third, we included cases, in which a specific example refers to the wrong process (e.g. bees carry the seeds).

> A bee sucks nectar from a flower and the seeds of a female plant stick on its body. Eventually it lands on a male flower and pollinates the stigma. It works also without bees if the wind blows the seeds to another plant. [NQ_6B_23]

> A bee sucks pollen from a plant. Afterwards, it flies to a place of its choice and empties its proboscis. After a while, a new plant can grow. [Drawing shows emptying on the ground] [BQ_4_17]

> Bees collect nectar and seeds stick on their body, which they will eventually loose while flying. [...] [Drawing in Appendix 2] [NQ_1_21]

(7) **Students describe pollination and seed dispersal separately ('Pollen/Seeds')**

This type comprises all answers describing both processes separately in a way that the connection between the processes is not visible. This can be the case when students use different examples to explain pollination and seed dispersal. In other cases, students describe pollination and seed dispersal as two different ways of reproduction. The sketches were often separated by a line. However, the descriptions of pollination and seed dispersal are both biologically correct in contrast to 'Students mix pollination and seed dispersal'. The following quotations illustrate the range within this type.

> Bees are attracted by the smell and the beauty of the flowers. Pollen sticks on the bee's legs. The bee arrives at another flower and the pollen pollinates the female part of the flower. Birds eat seeds and disperse seeds when they excrete them. Dandelion clocks (and other) disperse seeds via wind. [Drawing in Appendix 2] [QM_8_17]

> Most plants/flowers are pollinated by bees. In this way, the plant reproduces. The American touch-me-not however, shoots away its fruits/seeds after being touched. [QQ_4_33]

(8) **Students describe pollination and seed dispersal within one plant ('Pollen & Seeds')**

This type represents the most complete answers, including correct descriptions of both pollination and seed dispersal in one plant. The answers range from short descriptions, which do not mention any connecting processes between pollination and seed dispersal, to detailed descriptions of the processes involved.

> A bee pollinates a flower; the flower disperses seeds in the wind; the seeds are bedded in the soil; a bulb develops; a plant grows. [Drawing in Appendix 2] [BQ_4_20]

> A plant flourishes. A bee comes to collect nectar and pollen from the anthers stick on the bee's legs. At the next flower, the bee strikes off the pollen at the stigma and the plant is fertilised. Afterwards, a fruit develops which contains the seeds. Those get to the ground via animals or ecological factors [sic!] where a new plant grows. [JX_8_24]

Overview of students' descriptions

The answers of all 228 students (100%) were assigned to these eight types (see Table 1).

Table 1. Types and number of students' descriptions sorted by the processes mentioned. Each student was assigned to only one of the types, except 'Alternative way' which was, in 14 cases, assigned additionally to another type.

Type	Absolute number of descriptions (n = 228)	(percent)
Students ...		
... give an unclear answer or answer is missing ('Unclear/Missing')	12	(5.3)
... describe only growth of the plant ('Growth only')	12	(5.3)
... describe an alternative way of reproduction ('Alternative way')	15 [sole]+14 [additional]	(6.6 + 6.1)
... describe only pollination ('Pollination only')	48	(21.1)
... describe only seed dispersal ('Seeds only')	54	(23.7)
... mix pollination and seed dispersal ('Pollen X Seeds')	51	(22.4)
... describe pollination and seed dispersal separately ('Pollen/Seeds')	16	(7.1)
... describe pollination and seed dispersal within one plant ('Pollen & Seeds')	20	(8.8)

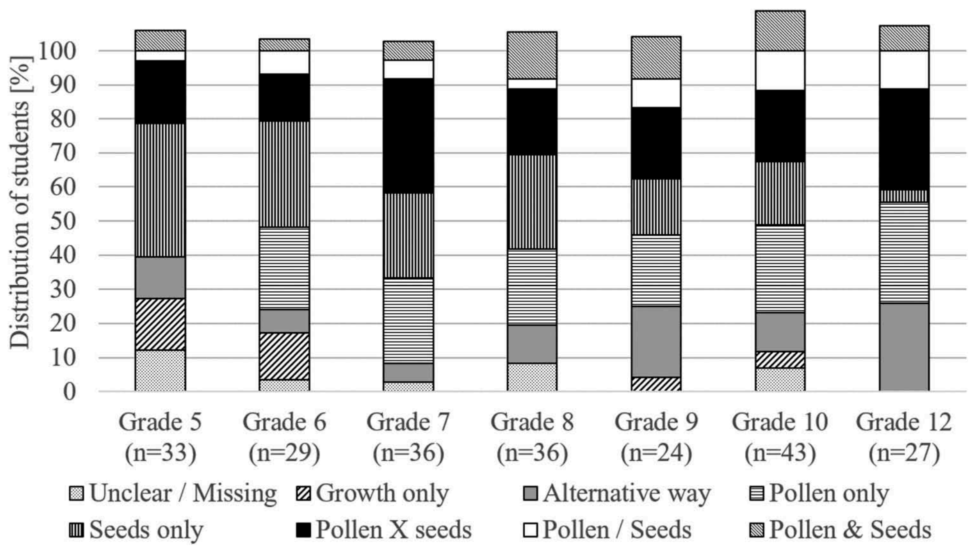

Figure 1. Overview of the eight types sorted by grades (abbreviations explained in 3.1.). Each student was assigned to only one of the types, except 'Alternative way' which was, in 14 cases, assigned additionaly to another type leading to bars with more than 100%.

The results show that only a small percentage of all students gave a correct description of plant reproduction including both pollination and seed dispersal (see Table 1). However, more than 60% of all students were able to describe at least one of these two processes correctly.

We further compared how the eight types are distributed in the different grades (see Figure 1). All conceptions are significantly not evenly distributed, neither between the age groups nor within one age group (Chi-Square between 20.72 and 103.02, $p < 0.05$).

The results show that the eight types can be found in almost all age groups. However, the distribution of the conceptions differs between the different grades. Most children were aware that reproduction and dispersal of flowering plants consists of specific processes, as the low numbers of missing answers and mere growth descriptions show. Remarkably, a substantial number of all students did describe only one of the processes involved in plant reproduction. Whereas younger students focused on seed dispersal, older students focused rather on pollination. A big difference between these two types of descriptions is that the 'pollination only' idea makes it difficult or even impossible to see plant reproduction as a cycle. On the contrary, many students mentioning only seed dispersal wrote about new plants growing from these seeds and drew a life cycle.

Discussion

The rate of students who mixed up the processes of pollination and seed dispersal was quite high in all age groups (13-33%). The lowest rates of mixing these processes were achieved in the 6th grade. This might be influenced by biology education at school since the Austrian curriculum includes the topic 'flowering plants' in 5th grade (Austrian Federal Ministry of Education 2000). Therefore, Austrian biology textbooks treat this subject in 5th grade including reproduction of flowering plants. Due to data collection at the beginning of the school year, the children of the 6th grade had probably learnt about this issue at school most recently. The first occurrence of the category 'Pollination only' in grade 6 may also be an effect of teaching in grade 5. The high rates of mixing the processes of pollination and seed dispersal within all grades indicates that students have difficulties connecting pollination and seed dispersal in a correct way, and are insecure in differentiating between these processes.

On the contrary, students of the two types 'Pollen/Seeds' and 'Pollen & Seeds' differentiate between these processes but connecting them still proves difficult for many students. This holds particularly true for students who see pollination and seed dispersal as two different ways of reproduction. Even students who do mention both processes in one plant describe barely what happens to pollen after being transferred. This lack of knowledge about the function of pollen could explain students' difficulties in connecting the stages of a flowering plant reported in prior studies (Schussler and Winslow, 2007; Benkowitz and Lehnert 2010; Quinte 2016).

An additional difficulty in the German language is that the term 'seeds' (German: 'Samen') is sometimes used synonymously for 'sperms' of animals. This is problematic, because seeds and sperms have different functions and represent different entities in the reproduction process. This problem originates from the word 'sperm' itself, which translates as 'seeds' or 'offspring' (Kattmann 2015). In English, the word semen is established for animal sperms whereas in German the original translation 'seeds' (German: 'Samen') is still common. This difficulty might increase the rate of mixing pollination and seed dispersal, but it is not the only reason since studies conducted in other languages describe the problem of mixing as well (e.g. Boyer 2000; Helldén 2000; Nyberg, Andersson, and Leach 2005).

In our analysis, we assigned all students using the term 'seeds' in the context of pollination to the type 'mixing pollination and seed dispersal', unless they explicitly compared 'seed cells' with animal sperms. However, we could not determine the 'severity' of mixing the processes because the word 'seeds' in the context of pollination could be just a flaw, but also indicate a profound confusion of pollination and seed dispersal. The same problem occurs with the word 'pollen' in the context of seed dispersal. What we can conclude from the data is students' insecurity in using the correct terms which can further lead to problems in understanding the differences and the connection between these processes.

Another interesting aspect comes from the study of Kissi and Dreesmann (2017) who created a 'flower hunt' in a botanical garden focusing on plant diversity, flower morphology and ecology. Many students within their study mixed pollination and seed dispersal; more than half of the students agreed with the statements 'plants grow from pollen' and 'seeds are needed for the pollination of plants' before and after the intervention. This implies that these students had a restricted understanding of the function of the flower even after the intervention; a probable indication of strong underlying conceptions. It also underlines the necessity to address the basis for the confusion of pollination and seed dispersal explicitly.

Astonishing is the fact that students' conceptions are apparently more or less stable during eight years of schooling. New terms are integrated into thinking (e.g. pollen much more after teaching in grade 5), but the conceptual growth towards acomprehensive scientific concept is not very successful in the total population. Interpreting the results from a learning progression perspective (Duschl, Maeng, and Sezen 2011), we can propose ideas about how students proceed in their understanding of plant reproduction. Students of the types (1)-(3) need to develop their knowledge about the biological function and about the consecutive order of the reproduction processes. Students who only mentioned one process (types (4) & (5)) might have a solid basis for learning but need to integrate the missing process in the right way. This integration is also missing in the types (6) and (7). Knowledge about the two processes of pollination and seed dispersal is only complete when students know the consecutive order and the function of each process. If the two processes are not connected, it is likely that learners confuse the processes or see them as alternative ways of reproduction. Students assigned to type (8) exhibited the most complete knowledge about plant reproduction, even though some aspects, particularly the connecting processes between pollination and seed dispersal (pollen tube growth, fertilisation, development of seeds), are still not present in most cases. In summary, the types can serve as 'lower anchors' and 'stepping stones' towards a more complete picture of plant reproduction, the 'higher anchors' (Duschl, Maeng, and Sezen 2011).

Summary & outlook

The results of the present study provide an overview of the processes students connect with plant reproduction. The study expands the existing knowledge using an open way of investigating students' conceptions that does not guide students' answers in a specific way. The presented data of students' conceptions of the processes involved can assist teachers when preparing lessons in a way that they explicitly take these conceptions into account.

Moreover, teachers can easily use the task to evaluate students' conceptions before teaching the subject. This short activity enables teachers to address students' difficulties and needs even more accurately. The task delivered a wide variety of conceptions in every grade and made students' think about possibilities of reproduction in plants. Teachers can use our 'types' to group students. Subsequently, students' answers can be used as starting points for discussions. In a second step, the task can serve as a tool to make effects of learning visible: Students can get their answers back after they have learned about the topic and rework their answers or add missing features in their explanations. We recommend providing a secret code (see appendix 1) to ensure anonymity, which can reduce students' fear of being judged for 'wrong' answers and encourages students to answer freely and honestly.

Finally, students can only understand the functions of flowers and fruits by considering the processes of sexual reproduction. This knowledge is crucial to comprehend the problems related to declining numbers of bees and other insects and hence probably leads to raising awareness for environmental issues. Therefore, the next steps of our work will be the development of learning materials that take up the results of the present study. The aim of these materials is to provide direct experiences with pollination and seed dispersal and the connecting processes. These materials will address specifically the problem of mixing the two central processes of plant reproduction and eventually allow to realise the full potential of plant reproduction in biology education.

Disclosure Statement

No potential conflict of interest was reported by the authors.

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Appendix 1: Task ‘Open description of plant reproduction’ [Original task is in German; Translations are not linguistically validated; Dots indicate space for drawing or writing; Original size is DIN-A4]

Plants manage to reproduce and spread although they are usually fixed in the soil.

How do you imagine the reproduction and spreading of plants?
Make a drawing first. You can also add captions in your figure if you want to.
Explain afterwards in words how you imagine plants’ reproduction.

Drawing:
...

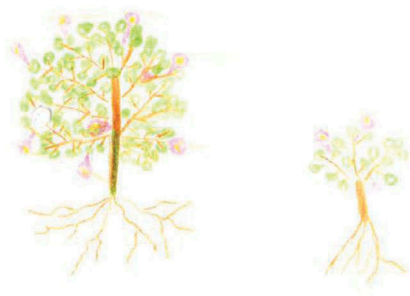
Explanation in words:
...

Secret code:**

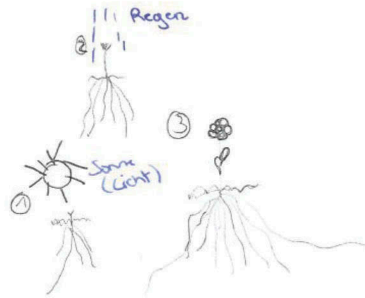
** Take the first letter of the first name of your mother and the last letter of the first name of your own. Add your house number. This code helps to match your answers without identifying you giving the answers.

Example: Mother ANNA; yourself: PETER; Privet Drive 4; Secret Code: AR4

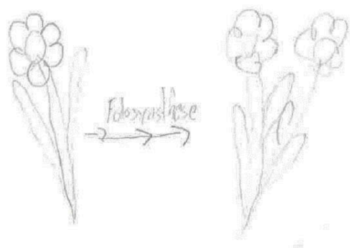
Appendix 2. The drawings belong to the quotations presented in chapter 3.1. Only one drawing was selected for each type.



"(1) Unclear / Missing": NQ_1_16

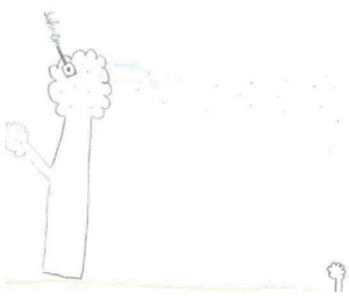


"(2) Growth only": BQ_5_15

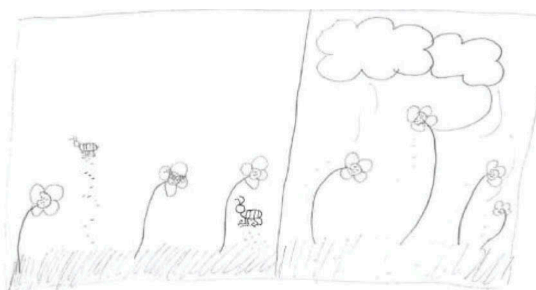


"(3) Alternative way": BQ_6_18

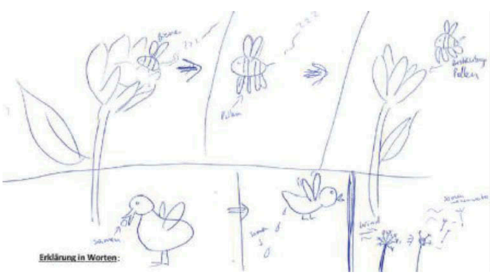
"(4) Pollen only": IB_2B_22



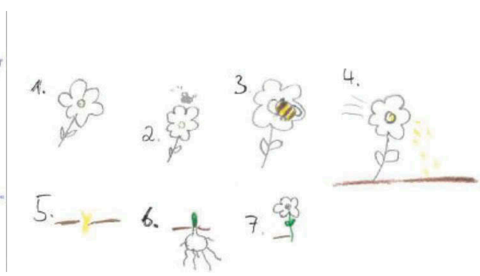
"(5) Seeds only": BQ_2_17



"(6) Pollen X Seeds": NQ_1_21



"(7) Pollen / Seeds": QM_8_17



"(8) Pollen & Seeds": BQ_4_20