Chapter 11
Where Do Plants Get Their Mass From? Using Drawings to Assess Adolescent Students' Modelling Skills and Their Ideas About Plant Growth

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11.1 Introduction

11.1.1 Modelling

Evidence-informed modelling is a vital element of scientific reasoning, and the competencies nurtured through modelling-based learning are part of the foundations of science education (Constantinou et al., 2019). Modelling broadens students' views of the world and teaches them to engage in scientific thinking about observable phenomena (Zimmerman, 2007). By developing and using models, students can learn to represent how scientific phenomena operate, test hypotheses and evaluate predictions. The construction and use of models enable students to develop an understanding of the mechanisms underlying phenomena. A scientific model also demonstrates a predictive function, enabling the user to predict changes and map out future behaviour in various aspects of a phenomenon (Nicolaou & Constantinou, 2014).

Drawing, as a mode of expression of students' ideas, enables the development of different representations of the same scientific concept, which in turn leads to creative reasoning (Ainsworth et al., 2011). The application of drawing-driven modelling can be used to support students' reasoning. Drawing-based modelling is particularly useful in school biology education (Brooks, 2009).

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Drawing can play an essential role in helping students develop a deeper understanding of biological concepts, such as photosynthesis. By creating visual representations of complex ideas, students can more easily grasp key concepts and develop an understanding of their interconnections. Through the act of drawing, students can also identify gaps in their understanding and negotiate misconceptions. Additionally, drawing allows students to communicate their understanding to others, and can serve as a valuable assessment tool for teachers. Overall, incorporating drawing into the learning process can enhance students' comprehension of biological concepts and promote a deeper appreciation for the mechanisms supporting phenomena in the natural world.

11.1.2 Photosynthesis

Photosynthesis is a process that is crucial for our planet, and very important in understanding the biology of plants and the processes that are taking place in sustaining ecosystems. Understanding photosynthesis involves developing a robust sense of how the process operates at both the micro- and macro- level of the organisation of biological matter and the facility to express those understandings at a symbolic level. Photosynthesis has been identified as one of the most challenging topics in biology education and one in which students encounter diverse challenges in their efforts to develop a robust understanding.

11.1.3 Students' Conceptions of Photosynthesis

Science education research studies of school students' understanding of the process of photosynthesis have been reviewed by Messig and Groß (2018) and by Russell et al. (2004), whose findings can be summarised as follows:

(a) students find photosynthesis to be conceptually difficult, a fact that often leads to a lack of interest and the emergence of misconceptions.
(b) students find it particularly difficult to visualise the process, or relate it to things they can observe, especially when the topic is presented purely as a molecular process or too many levels of representation are introduced at the same time.
(c) there are limitations to the practical demonstration of photosynthesis because the equipment is either unreliable and antiquated, or prohibitively expensive.

This study departed from the idea of invoking drawing as a medium for modelling-based learning to explore a potentially productive approach to support the development of adolescent students' understanding of the process of photosynthesis. We focussed on three age groups with the aim to explore the extent to which we could use students' drawings to identify how their modelling skills evolve across this age range and how their understanding of the mechanism of photosynthesis progresses.

11.2 Objectives

The aim of this study was to explore the extent to which we could use student-constructed drawings to identify how modelling skills evolve with age and how they relate to students' understanding of the mechanism of photosynthesis. To achieve this aim, we chose to work with students in grades 5, 7, and 10, i.e. from upper elementary, middle, and high school.

Our research questions were formulated as follows:

- Do students take into consideration the three functions of a model in their efforts to use drawing to express their understanding of the process of photosynthesis?
- How do age, interest, prior experience and knowledge about plants influence students' ability to model photosynthesis?
- What conceptions about photosynthesis do school students reveal in the process of modelling by drawing?

11.3 Research Design and Methodology

A total of 75 students took part in the study: 17 students from grade 5, 20 students from grade 7, and 38 students (2 classes) from grade 10. The participating students from grades 5 and 7 had just completed the curriculum-prescribed topic of photosynthesis. However, grade 10 students completed the tasks before participating in the teaching unit on photosynthesis that is offered for their grade level. None of the students had received prior teaching about modelling.

The research was carried out in three different schools covering the whole of the school education spectrum in Poland. The survey was anonymous, the students worked individually and were only asked to record their age, gender and class name. The research tool consisted of two parts, one with five questions, including two closed and three open-ended questions, and a task requiring students to make a drawing of the process of photosynthesis. In the first question, the students used a five-point Likert scale (from strongly dislike to strongly like) to express how much they like biology. In the second question, the students were asked whether they were growing plants at home. The next three questions were open-ended, and students were asked to provide short answers to:

- What is the role of plants in maintaining life on Earth?
- What life processes do plants carry out?
- What do plants do at night?

The open-ended questions were used to gain insight into students' personal knowledge about plants. Students were asked to work independently when answering the questions on provided paper with printed questions. Students' responses were coded using an iterative categorisation process of identifying suitable codes and checking for consistency and coherence in applying them to the whole dataset (Papadouris & Constantinou, 2010). The same responses were also checked for accuracy with respect to established scientific knowledge and points were given for appropriate answers.

Between responding to the open-ended questions and before the drawing activity, students were exposed to an introductory framing activity. The researcher presented them with two photographs, one of an acorn of a *Quercus robur*, and another of a *Quercus robur* tree. The following questions were addressed in a whole-group discussion: In what ways has this tree changed over the timespan of a few years? Can you identify as many changes as possible? What do you see? What might you assume? Where does a tree get its mass from? What do you think plants need to live? What might happen to stop plants from performing the processes that support life?

This framing activity served to introduce a problem situation and the discussion facilitated the creation of a common shared formulation of the problem. After the framing activity, students were asked to work individually to develop a drawing as an answer to the question: Where do trees get their mass from?

There were three aspects of assessment in this task, thanks to which it was possible to determine whether a given product meets the criteria for a scientific model or not.

11.3.1 Representative Function of Students' Drawings

The first assessed aspect of the drawings were elements that correspond to their *representative function*. The features of this function are divided into two groups: objects presented in the model and process variables. Drawings were coded for both features. For each depicted object and variable/process, students received one point. If the drawing depicted an object/variable connected correctly with other objects/variables, then it received two points. The detailed coding scheme used to analyse student drawings for this aspect is presented in Table 11.1.

11.3.2 Explanatory Function of Students' Drawings

The second evaluated aspect of the students' drawings was their explanatory function, i.e. their facility to provide an interpretation of how photosynthesis takes place. Table 11.2 presents the coding scheme and the anticipated exemplary answer, i.e. our reference framework, alongside the allocation of points (Table 11.2).

For each interpretive aspect (Table 11.2, 2nd row) that could be identified in each drawing, the student's construction received one point. Within explanatory functions, the main focus was to track students' ability to provide some kind of a mechanism that can be adapted to drawing as modeling. Thus, here we did not focus on

Table 11.1 Categories used to evaluate drawings in terms of the representative function of a model

Objects depicted in the model	Trait scoring
Plant	0 points: not included in the model 1 point: object included in the model with some incorrect connections with other objects 2 points: included in the model with correct interactions with other objects
Soil	
Water	
Sun	
Chlorophyll	
Glucose/sugar/starch	
Oxygen	
Carbon dioxide	
Nutrients	
Variables/processes	**Trait scoring**
Energy transfer Transport of water/nutrients/starch	0 points: variable not identified 1 point: variable identified with some incorrect effects 2 points: variable identified correctly with appropriate influences on other variables or objects
Growth – Size of the plant	
Chemical reaction producing glucose Role of sunlight in sustaining the chemical reaction Gas exchange	

biological correctness or language. We scored responses based on whether they indicated student awareness of a mechanism that can somehow explain the phenomenon. We ignored issues of terminology or language (for example using the term "duct" in place of "vascular tissue") and we refrained from assessing understanding of concepts that were not directly relevant to an underlying mechanism that the student was seeking to describe.

11.3.3 Predictive Function of Students' Drawings

Finally, students' drawings were also coded for their facility to serve a predictive function, the third defining feature of a scientific model. Table 11.3 presents examples of predictions that we would anticipate as possible aspects of students' drawings. In coding for this third aspect, we looked out for any information about a future event or any form of anticipated change and the conditions under which it might emerge. Very few drawings included information that alluded to predictions or the facility to use the drawing/model to make predictions. For this reason, in our coding, we simply recorded the predictive features, where present. For predictive functions, the main focus was to track students' ability to provide some kind of a prediction, hypothesis or educated guess that can be adapted to drawing as a modeling medium. Thus, here we did not focus on biological correctness or language. We scored responses based on whether they indicated some (potential) use of the model to formulate one or more predictions related to future changes in the phenomenon.

Table 11.2 Exemplary version of student response and grading points

Exemplary student response with some misconceptions
Water is transported from soil to the ducts of the root and from the ducts of the root shoots to the leaves, where a chemical reaction takes place with CO_2 absorbed from the atmosphere. This reaction, facilitated by the sunlight that binds to the chlorophyll in the leaves, produces glucose, needed for plant growth, and oxygen, which is released into the environment. Glucose is converted to starch to be stored. At night, when photosynthesis stops, glucose is transferred to other parts of the plant through the ducts of the shoot. If the amount of water is too high, then the leaves will produce excessive amounts of starch and the plant will overheat. Conversely, inadequate amounts of water lead to the production of insufficient glucose and the plant becomes undernourished. The increase in the mass of the plant is due to the carbon left over from the chemical reactions. Mineral nutrients from the soil are dissolved in the water absorbed by roots and transported through ducts to those parts of the plant (trunks, branches, leaves and roots) where the nutrient plays a role in cellular processes and plant growth
Elements of the mechanistic story – explanatory functions (with points allocation):
1. Water absorption: water is transported from soil to the ducts of the root (1) 2. Water transport: water is transported from the ducts of the root shoots to the leaves (1) 3. A chemical reaction takes place in the leaves; water and carbon dioxide are involved (2) 4. CO_2 is absorbed from the atmosphere (1) 5. This reaction is facilitated by sunlight (1) 6. Sunlight binds to chlorophyll in the leaves (1) 7. The reaction in the leaf produces glucose, needed for plant growth, and also releases oxygen into the atmosphere (2) 8. Glucose is converted to starch for storage (2) 9. Glucose transfer to other parts of the plant (1) 10. Glucose transfer takes place at night, when photosynthesis stops, through the ducts of the shoot (2) 11. The increase in the mass of the plant is due to carbon left over from the chemical reactions (2) 12. Nutrients that are in the soil are absorbed by roots and transported through ducts to all parts of the plant (2) 13. Glucose/starch provide the energy needed by the plant. Nutrients play a role in the biological processes inside the plant cells (2)

Table 11.3 Examples of possible predictions that we recorded students alluding to in their drawings

Prediction	Points allocation
If excessive water is available, leaves will produce too much starch and the plant will overheat	2
If inadequate amounts of water are available, the plant will not produce enough glucose and will become undernourished, i.e. it will not have enough energy to grow or support the cellular functions	2
Plants that are facing the sun for more hours are more likely to grow faster	1

Even if a response included biologically incorrect or inaccurate claims – for example “If excessive water is available, leaves will produce too much starch and the plant will overheat”, we focused on assigning points for the display of predictive power of the modeling ability, not for biological knowledge. For this particular example, the response did not receive points for representative power (since it is biologically incorrect), but we did deem that the response was indicative of the student's understanding that modeling practice includes the formulation of predictions.

11.4 Results

11.4.1 Analysis of the Students' Conceptions Based on the Questionnaire Data

In the open-ended part of the questionnaire, the first question was dedicated to the explanation of the role of plants in maintaining life on Earth. Most students (61%) received 1 point in this task. Sample answers were *Plants give food; Plants produce oxygen; They clean the air; They decorate rooms; They absorb carbon dioxide*. Two points were obtained by 23% of the respondents. One student who received the most points, i.e. 5, wrote down the following answers: *They produce oxygen; They take in carbon dioxide; They purify the air; They give fruits and vegetables; Some plants have a healing effect*. Three students, i.e. 4% of the respondents, did not receive any points in this task.

In the next question, the students were asked to list plant processes that support life. Furthermore, in this task, students received one point for each written answer. There were two students (3%) who did not provide any answer to this question. 25% of participating students received 4 points. One student got the maximum number of points (8) for vital functions, such as respiration, nutrition, reproduction, growth, excretion, development, movement and receiving stimuli. Students most often mentioned that plants grow (54 responses, 72% of participants). The least frequent answer was that plants react to stimuli: only 17 students (23%) included the response to stimuli in their answers.

The last task in the first part of the study was for students to describe what they thought plants do at night. 49% (36) of the respondents scored 1 point and 23 students (31%) scored 2 points. Two pupils (3% of participants) received 4 points in this task. The most frequent correct answer was that plants grow at night; such an answer was found in 20% (15) of the responses. From the students' responses, the largest group of answers indicates a misconception that plants produce oxygen at night (over 20% of respondents). Only 7% of respondents pointed to breathing and 15 (20%) to growth. 13% (9) of respondents indicated that plants sleep at night.

The coding of students' responses also showed that younger students tended to focus more on phenomenological features of plants and less on life processes. Younger students were more likely to only mention water as a pre-requisite to plant growth. Some also mentioned soil and in fewer cases alluded to its 'richness'. More sophisticated responses became more prevalent in the higher age groups and were more likely to identify water, carbon dioxide and light as necessary factors for plant growth. In grade 7, the process of photosynthesis was identified far more commonly than the process of respiration. Only a minority of the older, grade 10, students could associate plant growth with the dual processes of photosynthesis and respiration and identify the reactants, environmental conditions, and the products for both processes.

11.4.2 Analysis of the Students' Models

Through their drawings, most students demonstrated a good facility to visualize the process of photosynthesis, at least in its most basic elements. Every drawing was based on the student's own knowledge and experience. The students' drawings included rich information representing aspects of the process of photosynthesis, including participating objects, relevant variables and processes. Many drawings included some interpretive information about the workings of the process of photosynthesis and in a small number of cases we could identify connections with the process of cellular respiration and with plant growth. Predicting changes to the process of photosynthesis following specific stimuli, e.g. changes in the environmental conditions (Constantinou et al., 2019), or even changes to plant growth were much rarer. This is a limitation of this study, which we attribute to the preparatory framing activity that preceded the drawing/modelling activity: no reference was made in that activity to the process of making predictions, and their significance in science was not referred to either. In a follow-up study we intend to remedy this, in which case we expect that we would have more evidence to work with in terms of students' ability to use models to formulate predictions. Below we present findings for each of the three aspects of a scientific model, as revealed through our analysis and coding of students' drawings.

The students' drawings revealed the richest information and obtained the highest number of points in the category related to the representative function of models. This indicates that participating students found it easy to represent features of photosynthesis and plant growth. A variety of elements were represented in the students' drawings, such as plants, water, sun, soil, oxygen, carbon dioxide, and nutrients (Fig. 11.1). In addition, the rich phenomenological information represented in students' drawings may reveal that the act of drawing is more conducive to representing aspects of the phenomenon than to expressing explanatory features (Tsivitanidou et al., 2018). An example of a student produced drawing is presented in Fig. 11.1.

She is very fond of biology and grows plants at home. Evaluation of the model: representative function – 12 points (objects: plant, soil, water, sun; variables/processes: plant growth); explanatory function – 1 point (arrows suggesting plant growth); prediction – 0 points.

80% of students' drawings contained explanations about changes in weight expressed in kilograms or arrows, suggesting plant growth is a consequence of the process of photosynthesis. A rare explanation captured in student models was information about reactants and products of the photosynthesis process and their role in

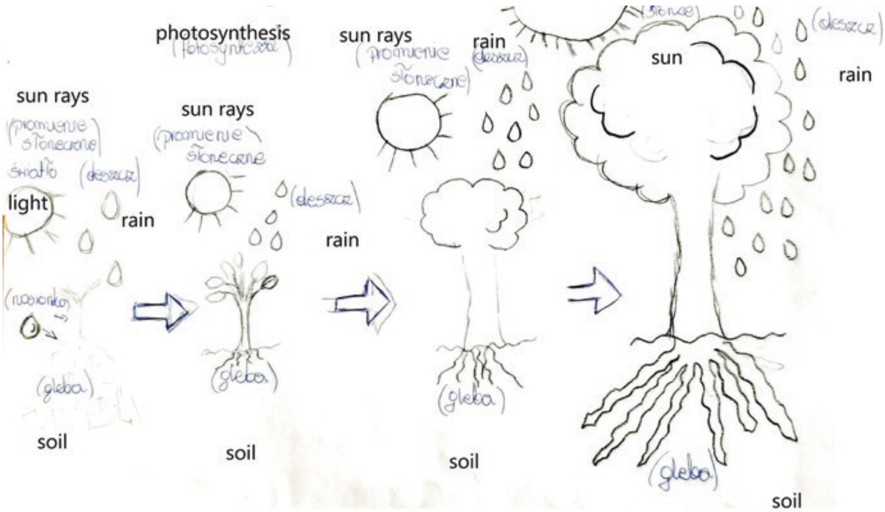

Fig. 11.1 Drawing produced by a student from Grade 7

Table 11.4 List of interpretations given by students, which were used to score the explanatory function of drawings

No.	Explanation
1	Plant size changes as a consequence of photosynthesis (e.g. arrows, weight in kg)
2	Indication of the reactants of photosynthesis (carbon dioxide, water), with information that these are needed for glucose production during photosynthesis
3	Providing the names of the products of the process of photosynthesis (food, glucose, oxygen)
4	Additional explanations: * Uptake of water from the soil through the roots * Uptake of nutrients (ions) from the soil through the roots (Morgan & Connolly, 2013) * Energy from the sun's rays (Papadouris & Constantinou, 2011) * The effect of temperature on the process of photosynthesis
5	Respiration as the process of breaking down glucose/food to release energy that is a necessary pre-requisite for plant growth. Where and when this process takes place. Release of carbon dioxide

supporting plant life. This explanation was found in 10 drawings (approx. 13% of the participating students). This is consistent with the prevalence of these processes in the students' responses to the open-ended questions, an example of triangulation that strengthens the credibility of this finding.

Table 11.4 presents typical categories of actual students' explanations that were scored based on the coding scheme of Table 11.2. The categories are presented in order of increasing complexity.

We identified only two elements that could indicate predictive functions in the student constructed models. These were: (1) Drawings that included the rings of annual increments (growing ring or tree-ring dating) and explaining that a new wood ring arises every year, from which we can know the age of the tree. These students explicitly identified that the older a tree is, the more wood rings it will have. (2) Drawings that included some indication of time (e.g. a clock), and the explanation that the tree increases its mass over time; so, the more time passes, the bigger/heavier the tree will be.

In summary, students' drawings were relatively lacking in the interpretive and especially the predictive functions. The most common interpretation that was identifiable in the drawings (approx. 80%) was the explanation of the change in mass, commonly illustrated with arrows indicating plant growth or expressing mass in kilograms. Only four drawings contained elements that could be identified with the function of prediction. These were comments about the fact that new tree rings grow every year and after cutting down the tree, you can count how old it is. In Fig. 11.2, this idea is illustrated with a drawing of a representation of a cross-section of a tree trunk, illustrating that, over time, the tree grows in weight and the more time passes, the bigger the tree will be (Fig. 11.2). A similar idea was presented in Fig. 11.3, where the student notes that after years, the mass of the tree increases (Fig. 11.3).

She is very fond of biology and she grows plants at home. Evaluation of the model: representative function – 16 points (objects: plant, water, sun, glucose, oxygen, carbon dioxide, nutrients; variables: transport of materials, plant growth, exchange of gases); explanatory function – 4 points (arrows, reactants, products, additional descriptions); prediction – 1 point (information about the annual increment of a new wood growth ring and the possibility of counting how old the tree is).

She is moderately fond of biology and grows plants at home. Evaluation of the drawing: total representative function –10 points (objects: plant, soil, water, sun; variables: plant growth); interpretive function – 1 point (after years, the mass of the tree increases through the help of light); prediction – 0 points.

11.4.3 The Effect of Age and Personal Knowledge on Students' Drawings

In the statistical analysis of the data, a linear regression model (GLM) was developed. The dependent variable used was the sum of the points attributed to each student drawing for all three features of its function as a model. The regression model indicates a moderate relationship between the dependent variable and the predictors, i.e. age of students and the class they attend. Other variables turned out to be statistically insignificant: whether students grow any plants at home: $p = 0.2$; whether students like biology: $p = 0.3$. In addition, the students' gender had no impact on the results obtained in the survey ($p = 0.4$). The coefficient of specificity (r^2) calculated for this study was 0.246. This shows that the regression model

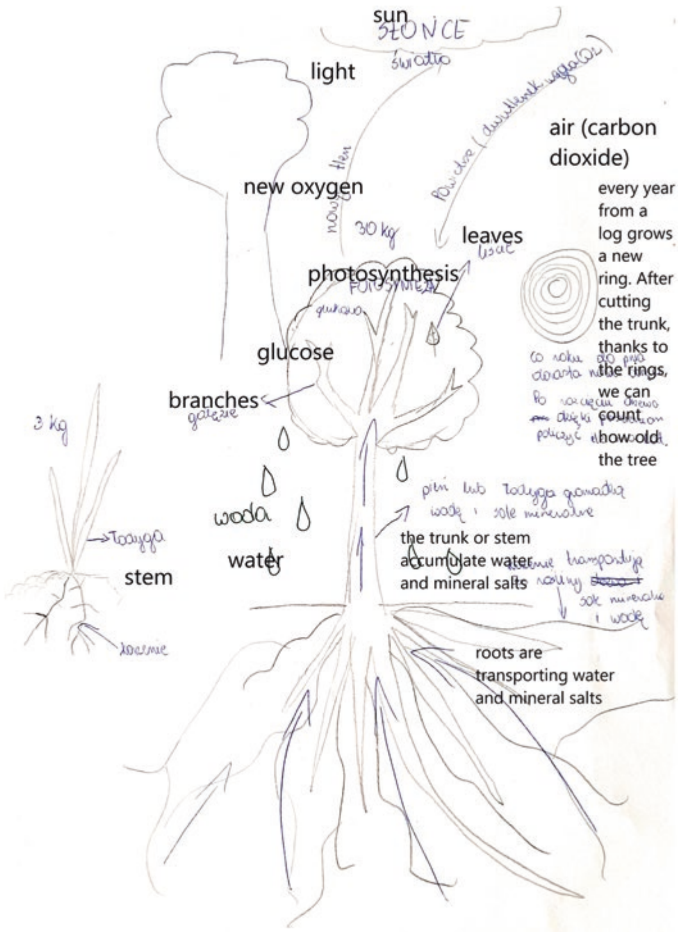

Fig. 11.2 Drawing model made by a student from Grade 10

stipulates that 24% of the variance of the dependent variable is explained by the independent variable at a significance level of $p < 0.01$. This is consistent with the sample size and the exploratory nature of this study.

Overall, our findings show that the richer the resources of personal knowledge revealed through the students' written responses, the more detailed and the more accurate their drawings were ($r = 0.86$, $p < 0.0001$). Based on these findings, we infer that the written text and visual representations complement each other concerning the knowledge and the thinking they reveal about the process of photosynthesis.

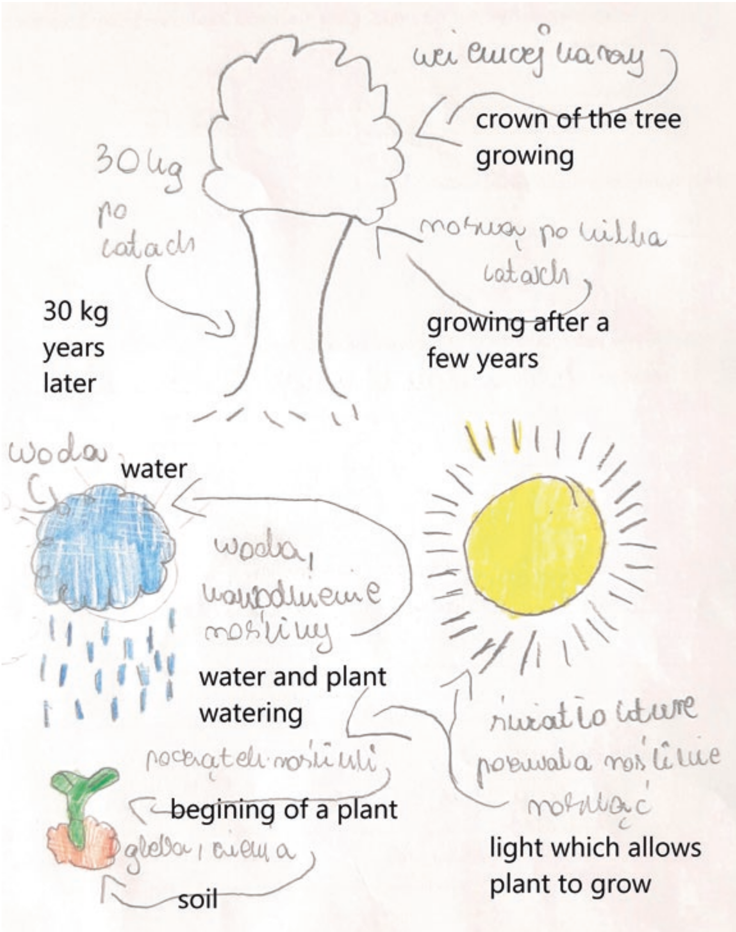

Fig. 11.3 Drawing by a girl in Grade 5

11.5 Discussion

Students' conceptions of the process of photosynthesis and their ability to construct models expressing the representative and interpretive aspects of their understanding of the phenomenon develop with age from upper primary through secondary education. The study confirms that the complexity of photosynthesis presents challenges for students in balancing the understanding of multiple processes and their role in a plant producing its source of energy. In addition, our findings reveal a strong dependence of the ability to model photosynthesis using constructed drawings on a student's knowledge about photosynthesis.

The presented research findings demonstrate that the richer the knowledge resources that were revealed in written verbal expression, the more accurate the students' drawings were, with more relevant details in representing the phenomenon of plant growth and interpreting the underlying mechanisms of photosynthesis and (more rarely) cellular respiration. It can therefore be argued that the verbal and visual communication complement each other. In other words, when students strive to develop and express their understandings, coherent information about their thought processes can be obtained by combining information from both text and graphics that are generated by the students (Lemke, 1998). In furthering our personal knowledge, we elaborate meanings, we manipulate connections between ideas and phenomena, and we express our understandings of these connections by resorting to the use of scientific concepts as epistemological tools. To acquire complete understanding of scientific concepts, we need to gradually develop the facility to move freely and consciously between the verbal channel and the visual, as well as between quantitative reasoning and symbolic mathematical logic, and between operational, localized sense-making and action (Aikens et al., 2021).

We note with interest that the resources revealed by the students verbally in this research study were also reflected in their graphical productions in ways that mostly cohere across age and maturation/educational level.

Moreover, the drawings which were more robust and accurate had more excessive written text in them. Those more complex drawings were rare, and students' explanations were basic and included alternative conceptions. Our findings demonstrate a correlation between students' age and robustness of drawings. This finding has also been observed in the past (Rybska, 2017).

Messig and Groß (2018) propose a novel way of teaching photosynthesis – one that starts the whole process from our anthropocentric point of view, in which we, as heterotrophic organisms, decompose the matter produced by plants so that the plants, from simple inorganic compounds contained in the soil and from the sun, can convert the sun's energy into the energy of the chemical bonds contained in the organic matter they produce. We acknowledge this proposal noting at the same time that, as illustrated in our work also, alternative conceptions tend to be persistent and do not disappear automatically with age or educational maturation. For example, students all the way to upper secondary education sometimes find the role of nutrients absorbed from the soil as difficult to grasp and tend to confound it with the process of 'feeding the plant or providing for its energy needs'. Morgan and Connolly (2013) address this issue and the need to differentiate between the outcomes of photosynthesis and its role in satisfying the need of the plant to have an energy fuel on the one hand, and the role of mineral nutrients absorbed through the soil in sustaining the biological processes that take place in plant cells, including in the release of energy by metabolising glucose.

Our study largely confirms that the act of drawing can serve as a resourceful part of scientific modelling activities. Scientific modelling includes three functions. In the presented research, students were able to fulfil the representational function to a greater extent. Objects and variables relating to the process of photosynthesis appeared in every one of the student-constructed drawings. Working with the inclusion of the other two functions of a scientific model turned out to be a more challenging task. As Upmeier Zu Belzen et al. (2019, p. 157) writes, tips and guidance from the teacher are essential to getting students through the modelling process, considering its three functions. Only with such support and experience can students develop an understanding of scientific models and modelling (e.g. Akerson et al., 2011; Gilbert & Justi, 2016; Schwarz et al., 2009; Windschitl & Thompson, 2006). In the presented research, students were not exposed to any special activities dedicated to developing the practice of scientific modelling, which probably influenced the appearance of a small number of drawings with a predictive level of modelling. Providing a scaffold in the form of a designed question turned out to be insufficient in most cases. As Karnaou et al. (2018) write, the process of constructing and interpreting models includes effective teaching practices that broaden students' understanding of science concepts and scientific modelling skills. Students' interest in working with models in the sciences assumes that models act as a link between theory and the discussed phenomena. In this work, we surmise that such a link was not obvious to many students. The findings demonstrate that to make this connection and to fully access the rich potential afforded by drawing activities as a context for modelling-based learning, a structured preparation would be necessary that would go substantially beyond our framing activity in explicitly developing ideas related to modelling and its emergence from applying theory to phenomena, and its utility in representing, interpreting and predicting aspects of the phenomena under study (Constantinou et al., 2019).

Fulfilling all three requirements (representation, explanation, and prediction) has also been shown in prior research to be a challenging task to achieve for most students (Karnaou et al., 2018; Cheng & Brown, 2015; Krell et al., 2014). Additionally, Krell and co-workers (2014) noticed that despite the global level of understanding of models, or aspect-dependent levels, important elements are students' understanding of aspects, such as the nature of models, multiplicity of models, the purpose of models, model evaluation processes, and changing models. In their research, they noticed that students seem to have a complex and at least partly inconsistent form of understanding of models. Students with high nonverbal intelligence and higher grades (indicating stronger personal knowledge) seem to have a more reliable and more expanded understanding of models and modelling than students with a less robust understanding of the phenomena under study. This study confirms these findings and also illustrates the need for further research before we can claim to fully understand how we can enculturate students into the scientific practice of modelling and have the assessment approaches to know when we do so effectively.

11.6 Conclusions

Our findings demonstrate that participating students have a certain amount of personal knowledge about plant life and the process of photosynthesis, and that modelling through drawing enables students to reveal this knowledge. During the modelling process, students focussed mainly on the representation of phenomenological aspects, including relevant objects and variables. Explanatory details were also present, but more rarely. Where they did exist, they provided richer information about student thinking and understanding. Predictive functions received markedly less attention in the students' drawings, possibly because participants were not prompted to think about dynamic changes in the preparatory framing activity. The findings confirm that the participating students from all levels of the school educational system are not familiar with modelling principles and that there is a strong need for enriching the curriculum and instructional tools and approaches with structured modelling-based learning activities if we are to claim that scientific practices are nurtured in ways that promote learning, autonomous thinking and creativity.

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