Science Education International
33(2), 213-223
https://doi.org/10.33828/sei.v33.i2.9

ORIGINAL ARTICLE

Elaboration of Practical Diagnostic Competence in Context of Students' Conceptions on Plant Nutrition

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ABSTRACT

Dealing with students' conceptions is one of the central elements of student-oriented teaching. To be able to organize learning processes efficiently, it is necessary to look at the learners in a differentiated way and to approach their conceptions individually. The first necessary step is the individual diagnosis of each student's conceptions. This article presents a qualitative study (n = 8) that focused on the development of drawing assignments for the diagnosis of conceptions on the topic of plant nutrition. Based on the conceptual metaphor theory (CMT), features were identified that are beneficial for the diagnosis of the conceptions. To achieve this goal, it was crucial to reliably diagnose existing conceptions with valid assignments, which can also be carried out in schools. Research about task design and the proceeding diagnosis of conceptions in the light of the CMT has received little attention so far. This article, therefore, deals predominantly with the question about the design of assignments in the context of conceptual change. Based on this, guidelines were derived for the design of assignments for practical use in science education. This study represents the basis for developing a Moodle-based digital learning environment for working with students' conceptions on the topic of plant nutrition in schools.

KEY WORDS: Students' conceptions; diagnosis; drawing; conceptual metaphor theory; plant nutrition; think-pair-share; peer interaction

INTRODUCTION

Dealing with students' conceptions in a way that facilitates learning is a central challenge for science teachers (Duit et al., 2012). However, teachers purely creating cognitive conflicts or presenting "alternative" viewpoints often do not achieve the effects they might have intended. It seems that methodology and student activation play an important role: In particular, the think-pair-share method (TPS) or techniques based on it seem to be a suitable way to enable learning progress in the broader sense of a transformation of conceptions (Gok, 2018; Lasry et al., 2008). TPS has been around for many years, but the understanding of the formation of students' conceptions is in constant evolution. While the first steps in understanding how to work with conceptions were based on purely cognitive approaches (e.g., Strike and Posner, 1982), other elements, like motivational aspects, were gradually added as important factors (Zembylas, 2005). This article is part of a larger study to develop a digital TPS-based classroom application to support science teachers and, at the same time, allow a glimpse on the mechanism of the transformation of conceptions. The focus of this article is on the first step necessary for working with students' conceptions – the diagnosis of conceptions cultivated by learners. A special condition for the diagnostic tool is its suitability for use in real teaching scenarios as well as in research settings. In contrast to a research scenario, the time a teacher can spare for diagnosis is rather limited. However, the required accuracy of the diagnosis is also limited for it only needs to enable a suitable workflow in the classroom.

THEORY

To develop a diagnostic tool to identify students' conceptions, clarity about the term must first be established. The idea is embedded in the theory of moderate constructivism (Duit and Treagust, 1998; Phillips, 2000). In that sense, a conception represents a self-constructed reality that most likely differs from one individual to another. Since the exact description of a reality is almost infinitely complex, its diagnosis is accordingly unrealistic. However, a hierarchical order can help to classify and structure students' conceptions into different levels of complexity (Figure 1). Normally, students have no difficulty in memorizing words and reproducing them when needed. When asked about terms – that is, the meaningful relation between words – differences in students' expressions due to previous knowledge reveal themselves. It is no longer a question of whether something has been memorized but rather of how a cognitive network was formed. Complex connections represent a combination of several terms (based on Johann et al., 2022). These are referred to as concepts. Concepts of individuals on a specific topic can differ not only in the way their constituent terms are linked but also in the understanding of the terms themselves. Terms as well as concepts are different forms of conceptions. In our language use, several concepts form superordinate notions – central conceptions about a content-

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33(2), 213-223
https://doi.org/10.33828/sei.v33.i2.9

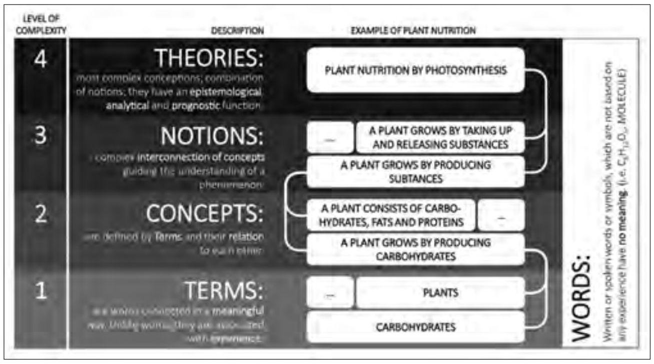

Figure 1: Hierarchical order of conceptions of different levels of complexity with examples on the topic of plant nutrition. While words and other symbols are no conception themselves, they are the building blocks of our verbal communication. Terms can be identified by a meaningful connection of several words and thus indicate the first level of conception. The three dots stand for the possibility of more (than two) elements forming a conception of the next level. Based on Odgen and Ivor (1923), the model categorizes different types of conceptions and does not represent a chronological progression (Johann et al., 2022)

related matter. These, in turn, can be combined into theories to explain a complex phenomenon (Figure 1).

One should, therefore, think that the variety of conceptions with which different people think about a topic is very large. In fact, however, the opposite is the case. Among many others, studies on the topic of science education (e.g., Kattmann et al., 1996; Messig and Groß, 2018) conclude that people often use few conceptions in constructing subjective realities. In the classroom, this becomes evident when the same learning barriers reveal themselves for a particular content time and again. To illustrate this and explain the origin of such conceptions, examples from the subject of biology are elaborated on in the next paragraph.

A broad body of studies has identified typical students' conceptions in various biological aspects. For instance, recent species of monkeys are often seen as the ancestors of humans (Harms and Reiss, 2019), or plants grow by taking up nutrients from the soil (Messig and Groß, 2018). Students have no experience of either evolution or plant nutrition; they are not directly accessible from their everyday lives. If they are confronted with them, they have to imagine something highly abstract. The conceptual metaphor theory (CMT) (Johnson, 2008) states that such notions can only exist due to a synthesis of accumulated experience. It emphasizes that human cognition is based on sensory-motor experiences like our moving body in space or our experiences with objects we touch, see, and other sensory experiences. To illustrate this fact, please make the following thought experiment: A starfish (if it could think and speak like us) would never say "I look back on past events" because its centralized and symmetrical body has no front and behind – just top, bottom, and sides. Another example: A slug would probably rather "taste an idea" than "grasp an idea" because it has no hands.

Ontological experiences based on our body's structure and functioning form thinking patterns, which are represented in a human's neuronal circuitry – the so-called image schemas (Gallese and Lakoff, 2005; Hampe, 2008). These image schemas are, therefore, embodied conceptions and can be conceived directly (Gropengießer, 2007). Through them, we can grasp the perceivable world around us. Abstract subjects pose a particular challenge since they cannot be experienced directly. To cope with this problem from a neurobiological perspective, embodied conceptions are applied metaphorically to abstract subjects (Niebert et al., 2012). In this sense, metaphors form a bridge between embodied conceptions in the source domain and the abstract subject of a target domain (Rohrer, 2005). For example, the early childhood experience of crawling from point A to point B (image schema located in a source domain) is used to see various recent species of monkeys as "stations on the path of evolution" (image schema located in a target domain) of humans (Groß and Gropengießer, 2019) or plant growth has to happen humanlike by transporting substances from the outside, into the inside of a "plants body" (Messig and Groß, 2018). This way of neural bridging is called metaphorization (Lakoff and Johnson, 2003); they directly point to a used image schema. In both described cases, the image schema "source-path-goal" is used (Lakoff, 1990).

Considering these insights, it is not surprising that students who transfer their experience of food intake to plants struggle with understanding the concept of photosynthesis. Students have no experience with carbon dioxide nor are it visible or edible. Teachers must find a way to soften up the connection from a source domain to its target domain and then offer alternative metaphors promoting more suitable connections. A suitable assignment could give teachers insights into the metaphors used by the learners. From this starting point, students' conceptions could be dealt with in a deliberate and learning supportive way.

In the past 20 years, there have been numerous studies that have highlighted the central importance of student conceptions for teaching and learning in science education (e.g., Driver, 1989). Central criticism (especially from teaching practice) remains how this knowledge of students' conceptions can be effectively transferred into the teaching practice. A prominent way of dealing with students' conceptions in class is the TPS (Lyman, 1981). In the past, the value for the learning process of this system or methods based on it in science education has already been demonstrated (Bamiro, 2015; Gok, 2018). It gets its name because of the three-part process: (1) In the "think phase," the students work on a task individually. In the process, they reflect on their thoughts on the topic. (2) In the "pair phase," two students exchange their results from their individual work and agree on a mutual answer. (3) In the "share phase," the groups share their results with the rest of the class (Robertson, 2006). Kaddoura (2013) was able to demonstrate that the use of TPS promotes critical thinking. Our central hypothesis is that students will be able to at least engage with

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https://doi.org/10.33828/sei.v33.i2.9

alternative metaphors by critically questioning their point of view through the discourse with another student with different conceptions. For this reason, a method based on TPS will be used to facilitate changes in conceptions. To group each student in the "pair phase" with a partner with different conceptions, the individual's conceptions must first be diagnosed. The approach is to let the students' implicit everyday conceptions become explicit in the "think phase" and thus makes them accessible for diagnosis.

The process of learning is considered a change of conceptions (Chi, 2008; Duit et al., 2012; Kattmann et al., 1996) and may be observed both in the "pair phase" and in the "share phase." To achieve this goal, it is crucial to reliably diagnose existing conceptions with assignments, which can also be carried out in schools. Research about task design and the proceeding diagnosis of conceptions in the light of the CMT has received little attention so far. This article, therefore, deals predominantly with the question about the design of assignments in the context of conceptual change.

Within the past 30 years, there has been a lot of research done that aims to identify students' conceptions in a diverse range of biological topics such as genetics (Baalmann and Kattmann, 2001), ecology (Munson, 1994), and evolution (Zabel, 2007). Furthermore, in the field of plant nutrition and photosynthesis, students' conceptions are well described. Many studies point out that assimilation processes are poorly understood within all ages: In a study conducted with 13-year-old students, 26% of them were convinced that plants received all nutrients from their environment (Marmaroti and Galanopoulou, 2006). Furthermore, older students, too, faced severe problems when it came to explaining plant nutrition. In that context, Anderson et al. (1990) showed that 98% of the interviewed non-major college students answered that plants take their nutrition from the soil. Even elementary and high school teachers struggle in elaborating on the origin of wood (Barker and Carr, 1989; Eisen and Stavy, 1988; Krall et al., 2009). The topic "plant nutrition" was chosen because extensive knowledge has already been gained on this topic regarding prominent conceptions (Messig and Groß, 2018).

The main research question of this article is therefore:

- What characteristics must assignments have to promote a manageable diagnosis of conceptions on plant nutrition in science education classes?

RESEARCH DESIGN

Based on the theoretical background, the main research question can be divided into the following subquestions (RQ):

- RQ 1: How suitable are drawings as an assignment format for diagnosing students' conceptions about plant nutrition?
- RQ 2: What impact do different criteria (problem orientation, resources, and linguistics) have on the elicitation of students' conceptions?
- RQ 3: What conclusions can be drawn from RQ 1 and RQ 2 for teaching in classrooms?

However, before determining possible assignment formats and a precise diagnostic procedure, it is necessary to first turn attention to the participants of the study. Since the aim is to construct a diagnostic tool that can be used not only in research but also in the classroom, secondary school students who have already dealt with the topic of plant nutrition in science classes would be the participants needed. Due to the COVID-19 pandemic, the first condition could not always be met. The second condition, however, could be guaranteed for all eight participants. The test group (n = 8) contained two high school students (between 16 and 18 years) and six university students (between 18 and 22 years). The students have been chosen randomly without regard to their gender. All students agreed to the survey and participated voluntarily. All personalized data were made anonymous all of them were exposed to the topic of plant nutrition on several occasions during their curriculum: The concept of photosynthesis is first introduced in German schools in Grade 6. In Grade 8, photosynthetic organisms are described as autotrophic and juxtaposed with heterotrophic organisms. In Grade 10, production ecology aspects of plants and their general role as primary producers are discussed. Since education in Germany falls within the competence of the federal states, minor deviations are possible. This prior knowledge allows the completion of a subject-related task without a previous learning unit.

Assignment Format

To identify conceptions on an individual level, the assignments should offer a variety of possibilities for editing. At the same time, teachers should be able to make a diagnosis at first or second glance so that the tasks can also be used in the classroom. For teachers to use the results to structure the lesson afterward, it should be possible to complete the assignments in ten to fifteen minutes. To decide on a suitable assignment format, existing work was consulted (Table 1). So far, different types of assignment for identifying students' conceptions have been successfully tested (Kattmann et al., 2017).

Table 1: Different types of assignment formats with a short explanation (Kattmann et al., 2017)

Used assignment	Description and explanation
Card queries	Sentence fragments are given with the task of completing them in a sensible manner
Drawing assignments	Students are asked to illustrate a scientific phenomenon
Text assignments	Factual or narrative texts are produced to reveal students' perspectives
Organizing assignments	Terms or pictures are given with the task to arrange them depending on the context
Concept cartoons	Cartoon characters give statements and students are asked to take a stand
Scenario-based assignments	A phenomenon is described, and students are asked to find a scientific explanation
Extrapolation	An experiment is presented, and students are asked to extrapolate a possible outcome
Discussions on conceptions	Discussions in classrooms are used to reveal different conception to the teacher and fellow students

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From the selection in Table 1, drawing assignments are most likely to meet these requirements. In addition, drawing assignments were identified as particularly suitable for diagnosing students' conceptions (White and Gunstone, 1992).

What We Know about Conceptions of Plant Nutrition

There needs to be a way of diagnosis that allows for further research in this direction and at the same time enables teachers to use the results during a lesson for the ongoing class. For the research purpose, the diagnosis of individual conceptions should be as accurate as possible. For teaching in the sense of TPS (matching students with different conceptions), on the other hand, it is sufficient to identify distinctive differences between learners. In the following, we will explain why the latter represents a lower diagnostic effort.

As already mentioned, the topic of plant nutrition was chosen because a lot of knowledge about conceptions on this topic has already been gathered. For plant nutrition, not only frequently cultivated students' conceptions were identified but also the conceptions found were associated with their source domains (Messig, 2020). The resulting learning map (Figure 2) provides a detailed insight into a useful framework for categorizing participants' expressions for an individual and differentiated diagnosis.

To clarify the concepts that are only described in the map in bullet point form, they are described in more detail below (Table 2).

For the purpose of a quick diagnosis by a teacher during a lesson, this categorization is far too detailed and would take too much time to complete. While identifying the concepts, frequently taken learning paths became apparent. In relation to this, Messig (2020) identified points where particularly great difficulties in understanding, that is, transforming one's conception arose. They were called "learning barriers" and are marked in the map with numbers:

1. Is a distinction made between minerals and nutrients? If a distinction is made, it is possible to understand that plants (unlike our experience with human nutrition) do not need solid substances as a primary source of material for their growth (Leach et al., 1996).
2. Is gas exchange in plants understood as a result of photosynthesis and cellular respiration? Students often see oxygen release and carbon dioxide uptake as an "inverse respiration." This means that they understand the gas exchange of photosynthesis like the human gas exchange: "like breathing, only the other way round" (Stavy et al., 1987).
3. Is the material composition of the plant compared with that of other (animal) life forms? If so, the plant is understood to consist of carbohydrates, fats, and proteins. This lays the foundation for the question of the origin of these substances (Stavy et al., 1987).
4. Is a biochemical reaction understood as a change of substances? If so, it can be explained how a plant can produce fats and proteins from carbohydrates and does not need to take these substances in from outside (Marmaroti and Galanopoulou, 2006).

For further work in the classroom within the "pair phase" of the TPS, a grouping of students who have different conceptions on one of these points would be sufficient.

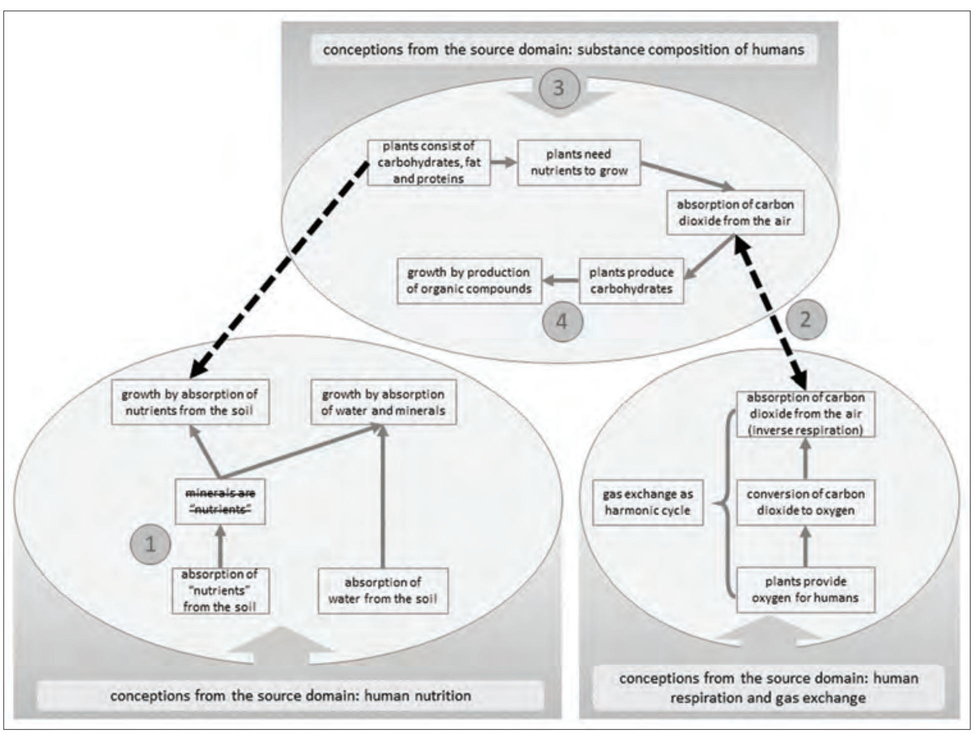

Figure 2: Map of conceptions, notions, and source domains concerning plant nutrition. Boxes: Concepts; boxes with rounded corners: Notions, arrows: Typical learning pathways; numbers 1–4: Typical learning barriers (Messig, 2020) (Text translated into English)

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DATA COLLECTION

The assignments, which were developed for this study, required the participants to explain plant nutrition by complementing a corresponding graphic with suitable drawings, arrows, and keywords. As pilot testing, the first drawing assignment was constructed with the help of colleagues and testing by single participants (not accounted for in the paragraph about the participants). From this point on, the following assignments were tested and adapted in the sense of design-based research (Baumgartner et al., 2003).

Figure 3 gives an overview over the chronological order of the tested assignments. First, pre-tests were carried out to develop a first well-functioning assignment (1). The assignments Drawing_1 helmont (2a) and Drawing_1 wordbox (2b) (Figure 4) were designed with different kinds of additional resources.

Design 2b proved to be less useful for diagnosing conceptions than design 2a and was, therefore, not pursued further. Design 2a, on the other hand, was developed to design 3 (Figure 5) by refining the wording of the assignment text. The assignment drawing_1 was designed in two versions, both containing additional material of different types: Drawing_1 worbox was supplemented by a list of more or less suitable words. The idea behind this was to offer participants suggestions for expressing their conceptions, but to prevent an effortless mapping of the words into the drawing template through obvious distractors. Drawing_1 helmont was complemented by an illustration of the historic experiment of Johan Baptista van Helmont and his results (Figure 6).

The Belgian scientist planted a willow tree (2.5 kg) in a plant pot with 90 kg of soil. He tended the plant for 5 years. After this time, he measured the weight of the tree and the soil. He found that the mass of the earth decreased slightly to 89.9 kg, while the plant gained about 82.5 kg. The measurement results were presented in a more extreme way to emphasize the effect. This supplementary material should offer the opportunity to reflect on one’s own conceptions based on the facts presented there.

The concept system (Figure 2) described in the last paragraphs served as our framework for analyzing the drawing assignments. Each student worked on only one assignment and took part in only one interview. Due to the circumstances caused by COVID-19, two interviews had to be conducted through video calls. Because the participants had no printing devices, the assignments were given to them digitally with the request to copy them by hand. Since performance does not play a role in the diagnosis of the conceptions, the participants were given enough time to complete the assignments (approx. 15 min and more if needed).

As a second data set, interviews (n = 8) were conducted to triangulate the results (Döring and Bortz, 2016). A researcher conducted the interview which was also divided into two parts: In the first part, the interviewer asked the participants to explain plant nutrition with their completed assignment. During this part, the interviewer did not ask further questions but encouraged the interviewee’s explanation with expressions of agreement. The aim of this part was to examine the statements of the participants with minimal influence of the interviewer. In the cases of the assignments “drawing_1 helmont” and “drawing_1 wordbox,” the participants received additional resources and another 10 min of working time before entering the second part of the interview.

In the second part, the interviewer used concept maps for the topic of plant nutrition (Figure 2). The interviewer located the statements made so far on the concept map and asked questions

Table 2: Conceptions regarding plant nutrition (based on Messig, 2020; Messig and Groß, 2018)

Conception	Description and explanation
“Nutrients” from the soil	The plant absorbs “nutrients” from the soil. “Nutrients” is not defined any further
Water from the soil	The plant absorbs water from the soil
Minerals are nutrients	The terms “minerals” and “nutrients” are not used synonymously
Nutrients from the soil	The plant absorbs fat, proteins, and carbohydrates from the soil
Water and minerals from the soil	The plant absorbs water and mineral salt from the soil
Plants consist of nutrients	The plant consists of fat, protein, and carbohydrates
Nutrients for growth	Fat, proteins, and carbohydrates are needed for growth
CO_2 from the air	The plant absorbs CO_2 from the surrounding air
Production of carbohydrates	The plant grows by producing carbohydrates
Production of organic compounds	Carbohydrates are the precursor for further biomolecules
Harmonic cycle	The gas exchange of the plant intertwines with the gas exchange from the living environment
Plants provide for humans	Plant produce O_2 to make human life possible
Conversion of CO_2 to O_2	The gas CO_2 is directly converted to O_2
Inverse respiration	The CO_2 absorption of the plant is the reversed respiration

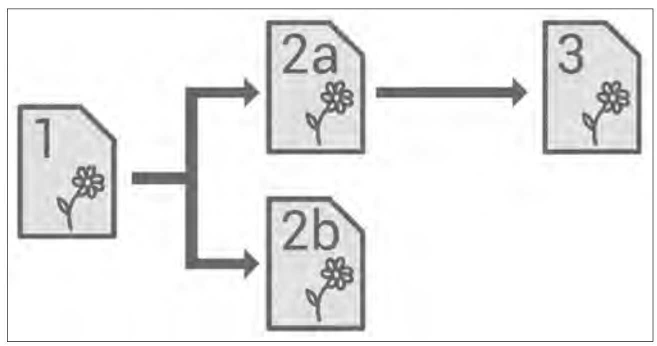

Figure 3: Sequence of assignments tested. (1) Pre-test (participants not accounted for in this study); (2a) assignment drawing_1 helmont; (2b) assignments drawing_1 wordbox; and (3) assignment drawing_2

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about aspects not yet addressed. Because each interpersonal interaction automatically results in unintentional interventions, only terms which were previously mentioned by the participant were used by the interviewer during this part of the interview. The aim of the second part was to identify conceptions which were not expressed in the first part due to their lesser relevance to the topic from the point of view of the participants.

The interviews lasted for about 30 min. They were audio-recorded and subjected to qualitative content analysis (Mayring, 2004) to identify the conceptions and underlying image schemas students used in each part of the interview. For reliability, coding and interpretation of students' statements were analyzed by three researchers working independently. The findings of all were then aligned if necessary. As a result, we were able to derive a guideline system representing the students' conceptions about the given assignments. Besides the identification of conceptions, statements were also interpreted in the context of the CMT (Johnson, 2008).

RESULTS AND DISCUSSION

In the following, all the conceptions found in the completed assignments as well as in the interviews are listed. While analyzing the gathered data, several important features concerning the diagnostic capabilities of the assignments became obvious. The identified conceptions are listed first and second examples are presented in terms of their significance for those features. For reasons of clarity, the examples for relevant features are immediately discussed under the respective heading.

Identified Conceptions

To provide an overview, the results of the assignments and the subsequent interviews are presented with regard to the conceptions listed in Table 2. To combine the results of the completed assignments and the interview in the same table (Table 3), we used gray tones (light gray and dark gray) to code our interpretation of the completed assignments and symbols (+ and -) to code our interpretation of the statements made in the interview.

The data collected at Table 3 show the following results:

- To show inconsistencies in our interpretation, statements were also documented which contradict one of the conceptions listed. Light gray cells containing a "-" and dark gray cells containing a "+" indicate a contradiction between the completed assignments and the statements from the interview. Overall, we encountered six contradictions
- In some cases, neither a statement from the completed assignments nor from the interviews is documented (marked with "/"). This is because the statements of the participants in question were interpreted as too ambiguous to be able to draw a clear conclusion
- Statements about the concepts associated with the four learning barriers are elicited to different degrees by the assignment (light and dark gray). While every participant expressed concepts on barrier 2, only 5/6 out of eight participants expressed concepts on hurdles 1 and 4. The fewest concepts were expressed in relation to hurdle 3 (two out of eight)
- In the edited assignments (seven out of eight) as well as in the interviews (eight out of eight) conceptions referring to the two major notions (Figure 2) were expressed.

Figures 7-9 show examples of the representation of conceptions in the completed assignments. They each present indications for overcoming one of the four learning barriers.

The first closer look at the data collected is to ask whether drawing assignments are a suitable format for diagnosing conceptions on the topic of plant nutrition (RQ 1).

Table 3: Expressed conceptions in the completed assignments and interviews. Light gray: Conception found in the completed assignment, dark gray: The completed assignment contradicts the conception, "+:" Conception found in the interview, "-:" Statements from the interview contradict the conception, and "/:" No conception found in the interview or in the assignment. The numbers 1–4 indicate the typical learning barriers (Figure 2)

		Drawing_1 helmont			Drawing_1 wordbox			Drawing_2	
	# participant	1	2	3	1	2	3	1	2
1	"Nutrients" from the soil	+	+	+	+	+		/	/
	~~Minerals are nutrients~~	-	-	-	+	+	+	/	+
2	Water from the soil	+	+	+		+	+	+	+
	CO_2 from the air	+	+			+	+	+	+
	Inverse respiration	+	+	/	+	/		/	/
3	Nutrients from the soil	/		/	+	/		/	/
	Water and minerals from the soil	+		/	+	+	+	+	+
	Plants consist of nutrients	/		-	-		+	/	/
	Nutrients for growth	+		+	+		+	+	+
4	Production of carbohydrates	+	+	+	+	+	+		+
	Production of organic compounds	-	-		-	+	/	+	+
	Harmonic cycle	+	+	-	+	/	/	/	/
	Plants provide for humans	+	+	-	-	-	/	-	-
	Conversion of CO_2 to O_2		+	-	-	-	/	/	/

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Drawing Assignments

If the results of the processed assignments are considered as a whole, it is noticeable that there are two different styles of editing. In some works, the drawing part predominates and in others the text part.

One example from the assignments “Drawing_2” (Figure 10) shows different types of arrows: Their meanings are “intake” (in the case of H_2O and CO_2), “emission” (in the case of oxygen), “process” (in the case of formation of plant substances), and “production and usage” (in the case of O_2 and glucose). This versatile use is complemented by the positioning of the arrows in relation to the tree. Whether consciously placed or not, the arrows suggest that water and minerals are absorbed from the ground while CO_2 is absorbed from the air.

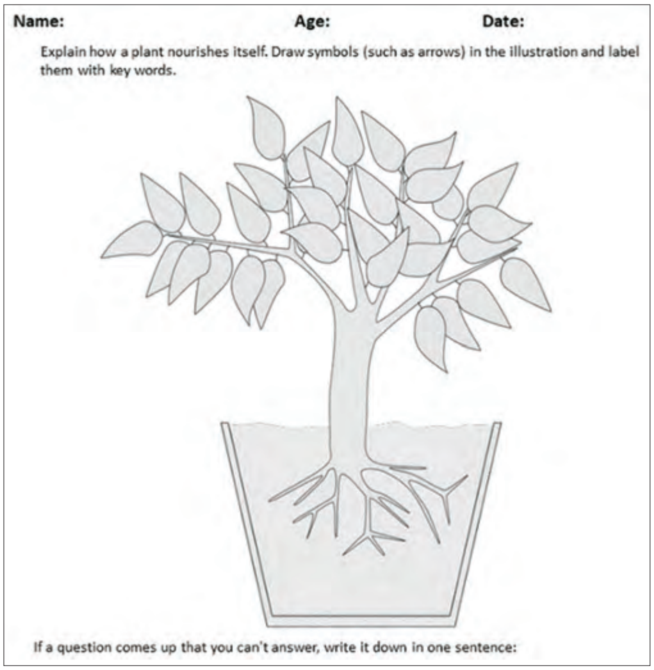

Figure 4: Assignment “drawing_1” (text translated into English)

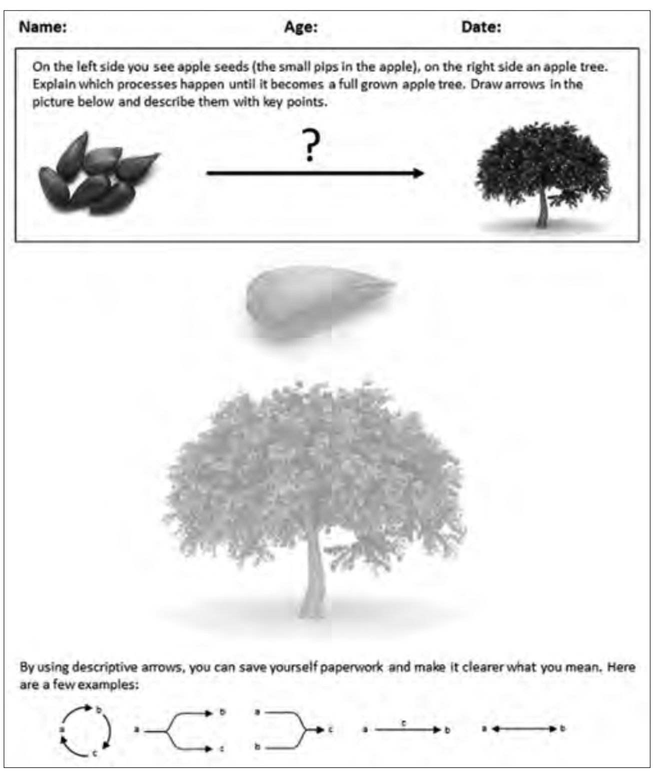

Figure 5: Assignment “drawing_2” (text translated into English)

In our opinion, this case provides clear indications of the better suitability of drawings/arrows compared to pure continuous text for identifying conceptions. The reason for this is the characteristic of arrows to connect at least two terms, which conforms to the definition of a concept. The nature of the connection can be represented by text or the type of arrow. To support the expression of conceptions, we, therefore, recommend drawing tasks.

However, besides the editing quality, another aspect of the results became apparent: The amount of editing of an assignment compared to the number of conceptions expressed. In the assignment “Drawing_1,” one participant explained plant

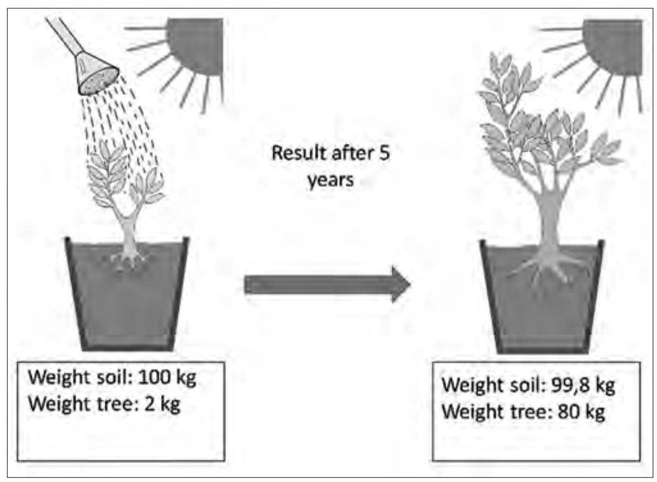

Figure 6: Additional resource “helmont:” Pictorial description of the experiment of van Helmont and its results (Text translated into English)

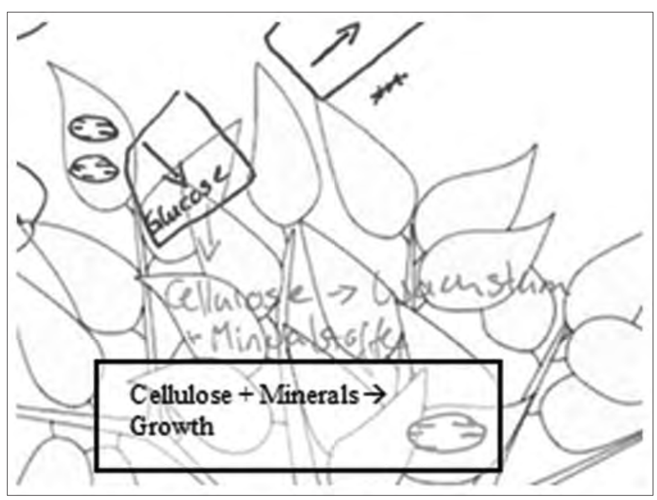

Figure 7: Learning barrier 4 probably overcome (text translated into English)

nutrition with words. The corresponding text is rather long and processes such as uptake and release of substances were described for every instance (Figure 11). The written paragraph in Figure 11 can be divided into three sections: (1) Location of photosynthesis, (2) chemical reaction, and (3) formation of biomass. The first few words could be simply replaced by the positioning of the word "photosynthesis" over a leaf. The chemical reaction gives no indication where the educts come from, and the products go. The last passage of the text is left unanswered whether the photosynthesis and the formation of biomass are seen as different processes. Since the products of the chemical reaction are phrased as "$C_6H_{12}O_6 + O_2$" and CO_2 is seen as a nutrient, which leads to the formation of biomass, it is unclear if "biomass" and "$C_6H_{12}O_6$" are conceived as the same thing.

Under the assumption that every item of the drawing would be written as text, the average size of the processed assignment "Drawing_1" would be around 10 sentences. If some elements were not phrased efficiently, it would probably be longer. Apart from non-native German speaking participants having a disadvantage, the editing process and diagnosis would take considerably longer. The data also show that participants who used drawings for editing, on average, expressed more ideas in the same amount of time.

Encouraging participants to use symbols (like arrows) rather than text made it easier for us to identify conceptions and therefore should be favored to text. For the diagnosis in class, this time saving could be important for a successful implementation within a lesson. Other clearly recognizable patterns in the results are presented and discussed with examples in the next chapter.

Example-Based Illustration of Important Features for Identifying Students' Conceptions

In the following, the results are presented according to the found features promoting the diagnosis of students' conceptions (RQ 2). The description of individual examples reflects the general results concerning the respective feature. They allow conclusions to be drawn on formal and educational requirements for assignments to diagnose student conceptions.

Problem orientation

The first feature of the tested assignments concerns the type of problem involved. This aspect revealed itself in the results of the assignments "Drawing_1 wordbox" and "Drawing_1 helmont." While task formulation of both assignments was identical, the employed additional resources were different. The results varied especially in the second part, after the additional resources had been used to complement the previous work. In the interview, it became clear that participants working with the resource "wordbox" did not use the given words to explain plant nutrition but to assign them to a place in their drawing. This resulted in them giving a mere description instead of an explanation (three of three participants) a representative example is shown in Excerpt 1:

Excerpt 1:

Participant:… *then there are the leaves because they are part of the plant. That is why I wrote "a leaf" here*

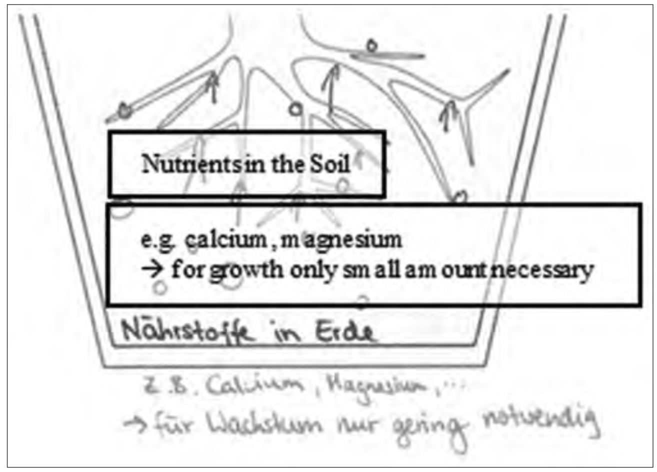

Figure 8: Learning barrier 1 probably overcome (text translated into English)

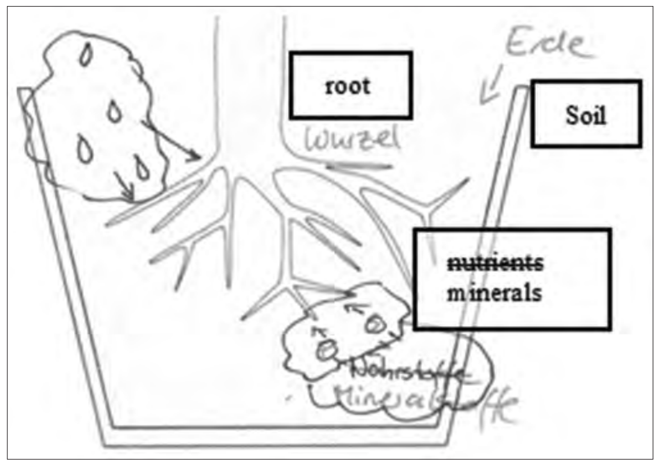

Figure 9: Learning barrier 1 probably overcome (text translated into English)

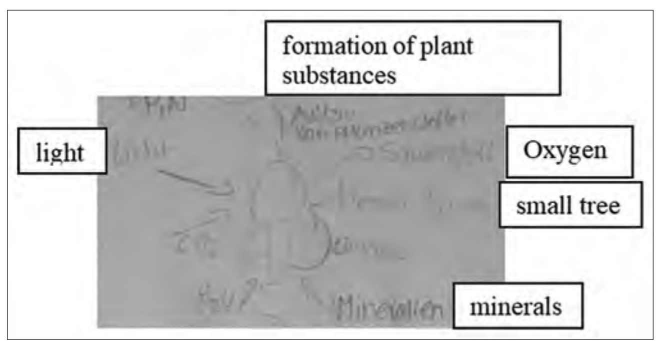

Figure 10: Part of a drawing from participant 1 of assignment 'Drawing_2' (text translated into English)

Interviewer: *You just looked: Which word fits where?*
Participant: *Precisely.*

On the contrary, those working with the resource "helmont" elicited reasoning (two of three participants). The participants used the experimental data to substantiate their conception of plant nutrition as shown in the following example:

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Figure 11: Part of the drawing from participant 1 of assignment "Drawing_1 wordbox." (Text: In the leaf (chloroplasts), the photosynthesis takes place. Conversion, heat, car, energy, and emission. The plant nourishes itself mainly through CO_2, which is converted into biomass afterward)

Excerpt 2:

Participant: *The nutrients are only marginally responsible for growth, as the weight of the soil decreases only slightly, the tree becomes heavier.*

According to our interpretation, the reason for the discrepancies between the two assignments "Drawing_1 wordbox" and "Drawing_1 helmont" lies in the problem orientation. It does not concern the task definition itself but the additional resources. The reasoning of the participants for the matching of the given words was no longer task related (Excerpt 1). It may have followed other rules such as "the more words that can be matched with the drawing, the better." Therefore, we conclude that the resource "wordbox" promotes a matching task rather than a real problem orientation.

On the other hand, the additional resource "helmont" elicited reasoning (Excerpt 2). In our opinion, this difference is due to the following reasons: While words and images can be linked in a purely associative way, the abstract illustration of the results of the van-Helmont experiment must be interpreted first. This requires reflection in a task-related manner due to the preceding engagement with the problem. Irrelevant factors, such as the number of branches of the plant or the color of the earth, are not taken into account. Both drawing assignments show that the additional resources "helmont" and "wordbox" are also part of or at least affect the employed problem. Since the goal of this study is the creation of assignments eliciting a more differentiate picture of the conceptions present in the students' minds, we suggest choosing problems over tasks and problems with predetermined goal criteria.

Additional resources

The next part of the results presented here concerns the use of additional resources in general. The assignments were only provided with additional resources, because these were later to help create a problem space for collaborative work (Barron, 2003) in the "pair phase." Besides being part of the problem, the assignments "Drawing_1 wordbox" and "Drawing_1 helmont" revealed another aspect of the additional resources: After working with the additional resources, four of six participants added at least four elements to their drawings. In the second part of the interview, four of six participants added at least three task-relevant sentences before signaling the end of their explanation with a pause.

According to our interpretation, the participants understood the additional material as a prompt for further processing, since it was only issued in the second step of the assignment. It may also have been seen as a guideline as to what was expected from them. In each case, the additional material led to the expression of further conceptions, which makes a more detailed diagnosis possible.

Since a larger number of expressed conceptions usually allow a more precise diagnosis of conceptions, we recommend generally adding task-relevant additional resources to the assignments. It is also easier for teachers to identify students with different conceptions in a limited amount of time.

Cognition linguistics based on CMT

In the next part, we took a closer look at the formulation of the assignments itself. The assignments "Drawing_1 wordbox" and "Drawing_1 helmont" contained the term "Ernährung" (nutrition). In four out of six interviews, the participants spoke exclusively of substance absorption before they signaled the interviewer to speak by taking a clear pause. One of six talked about substance absorption and energy and another one talked about energy and growth. Because of this, a second assignment about plant nutrition was designed (Drawing_2). It was formulated with the help of a graphic on which a seed and a tree could be seen (Figure 5). Instead of asking to describe plant nutrition, the phrasing "which processes happen until the seed becomes a tree" establishes the contextual link between the seed and the tree without using the term "Ernährung" (nutrition). Two out of two participants talked about substance absorption, energy, growth, and proliferation before signaling the end of their explanations.

Our interpretation of these results was guided by taking a cognitive linguistic look on the term "Ernährung" (nutrition) – something with which all participants have ample prior knowledge. Several different experiences are tightly connected to this term. The following list gives a few examples:

- Nutrition is the provision of food (Messig, 2020)
- Food provides energy (Anderson et al., 1990)
- The intake of food causes growth (Messig, 2020).

When a term like "Ernährung" (Nutrition) was used, notions like the ones listed above must be anticipated. In this case, it was evident that the participants had mainly the intake of food on their minds for explaining their drawings since they did not talk about other aspects of nutrition.

To get a representation of conceptions as holistic as possible, we suggest paying close attention on the formulation of the assignment. Students' conceptions arising from basic human experiences as well as conceptions fostered by the scientific community must be anticipated. Replace abstract terms with descriptive text and use pictures, if possible, to avoid a limitation of the range of expressed conceptions. On the other hand, a term for which preconceptions already exist can be used to specifically limit the spectrum of the students' expressions. This can be helpful in the context of long-term lesson planning.

Level of diagnosis

To show participants' individual understanding of plant nutrition, the method of diagnosis must be sufficiently resolving. In the case of the conceptions surveyed here, it is not possible to distinguish between single participants based on the notions they expressed because every participant expressed both major notions (Figure 2). The term "photosynthesis" is an example, which is why a diagnosis at the level of terms is also not suitable. "Photosynthesis" is understood either as a process of energy production, a process of sugar production, or gas exchange. If the object of diagnosis was only the term "photosynthesis," the differences just described would remain undetected. We, therefore, recommend a diagnosis on the level of concepts to enable a suitable compromise between depth of understanding and a diagnosis that is as individual as possible.

Schema corresponding arrow diagrams

Since the use of arrows to indicate relationships between terms has been so helpful in diagnosing conceptions, the use of different types of arrows should be encouraged. Therefore, example arrow diagrams were given in the assignment "Drawing_2" (Figure 5). They were designed according to the schemas commonly used as basis for the metaphors. Since they were not utilized by the participants, no conclusions could be drawn toward a possible benefit or downside.

Conclusions for Constructing Assignments

To help teachers design assignments to diagnose students' conceptions in the classroom (RQ 3), the following guidelines were derived from the gathered data:

- Design assignments which can be edited by free drawings or drawings on a template
- Design assignments with problems, which allow versatile approaches and a variety of results
- Provide metaphor-free (in the sense of judgmental) additional material in the form of experimental data or images that can be used to justify one's point of view
- If an assignment is intended to address a wide range of potentially existing conceptions, it is helpful to set the assignment with as few technical terms as possible. Use words that correspond to basic human experience (seeing, hearing,…) instead
- Diagnose students' conceptions on the level of concepts to resolve their individual understandings of the topic and reference them to the four major learning barriers (Figure 2).

For further research, we use the evidence-based guidelines to develop a "Peer Interaction" plug-in for digital learning platforms such as Moodle used in Germany. The guidelines for editable content presented here are used and expanded so that they are freely available to the public.

Limitations

Due to this qualitative research approach, the results of this study are not representative for students in general. However, with the CMT as a basis, the participants' statements allow conclusions to be drawn about general thought patterns (Heinze, 2001; Mayring, 2002) on the subject of plant nutrition. This means that the list of guidelines given here is most likely valid but possibly not complete. Furthermore, dependencies between features and their amount of influence on the overall result remain unclear.

While many conceptual metaphors are used culture independent, there are also culture-dependent metaphors (Kövecses, 2015). As a result, the cognition linguistic aspects of the assignment may need to be considered differently with students from other cultural backgrounds.

CONCLUSION

This work shows several aspects of how assignments can be constructed and improved to diagnose students' conceptions about plant nutrition. Working with students' conceptions in class is thus simplified or even made possible in the first place. The work draws particular attention to the importance of the language used and its implications. For most of the assignments used in German schools being text based, it also shows an alternative approach to assessing students' understanding of plant nutrition.

The research project was funded by the Joachim Herz Foundation, Hamburg. We thank the reviewers for helpful suggestions for improving the manuscript.

ETHICAL STATEMENT

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Therefore, we have decided to observe the DFG's Code of Conduct "Guidelines for Safeguarding Good Research Practice."

REFERENCES

Anderson, C.W., Sheldon, T.H., & Dubay, J. (1990). The effects of instruction on college nonmajors' conceptions of respiration and photosynthesis. *Journal of Research in Science Teaching*, 27(8), 761-776.

Baalmann, W., & Kattmann, U. (2001). Towards a better understanding of genetics and evolution-research in students' conceptions leads to a re-arrangement of teaching biology. In U. Harms, I. Garcia-Rodeja Gayoso, J. Diaz de Bustament, & M. Pilar Jiménez Aleixandre (Eds.), *III Conference of Europaen Resaerchers in Didactic of Biology* (Univeriade, Issue January, pp. 13–25). https://doi.org/10.13140/2.1.5076.8966.

Science Education International
33(2), 213-223
https://doi.org/10.33828/sei.v33.i2.9

Bamiro, A.O. (2015). Effects of guided discovery and think-pair-share strategies on secondary school students' achievement in chemistry. *SAGE Open*, 5(1), 1-7.

Barker, M.A., & Carr, M.D. (1989). Photosynthesis-can our pupils see the wood for the trees? *Journal of Biological Education*, 23(1), 41-44.

Barron, B. (2003). When smart groups fail. *The Journal of the Learning Sciences*, 12, 307-359.

Baumgartner, E., Bell, P., Brophy, S., Hoadley, C., Hsi, S., Joseph, D., Orrill, C., Puntambekar, S., Sandoval, W., & Tabak, I. (2003). Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher*, 32(1), 5-8.

Chi, M.T.H. (2008). Three types of conceptual change: Belief revision, mental model transformation, and categorical shift. In S. Vosniadou (Ed.), *International Handbook of Research on Conceptual Change* (pp. 61–82). Routledge.

Döring, N., & Bortz, J. (2016). *Forschungsmethoden und Evaluation Research Methods and Evaluation.* (5th ed.). Springer. Available from: http://www.lehrbuch-psychologie.de

Driver, R. (1989). Students' conceptions and the learning of science. *International Journal of Science Education*, 11(5), 481-490.

Duit, R., & Treagust, D.F. (1998). Learning in science-from behaviourism towards social constructivism and Beyond. In B. Fraser & K. Tobin (Eds.), *International Handbook of Science Education* (pp. 3–25). Springer.

Duit, R., Gropengießer, H., Kattmann, U., Komorek, M., & Parchmann, I. (2012). The model of educational reconstruction-a framework for improving teaching and learning science. In D. Jorde & J. Dillon (Eds.), *Science Education Research and Practice in Europe: Retrospective and Prospective* (pp. 13–37). Springer.

Eisen, Y., & Stavy, R. (1988). Students' understanding of photosynthesis. *The American Biology Teacher*, 50(4), 208-212.

Gallese, V., & Lakoff, G. (2005). The brain's concepts: The role of the sensory-motor system in conceptual knowledge. *Cognitive Neuropsychology*, 22(3-4), 455-479.

Gok, T. (2018). The evaluation of conceptual learning and epistemological beliefs on physics learning by think-pair-share. *Journal of Education in Science, Environment and Health*, 4(1), 69-80.

Gropengießer, H. (2007). Theorie des erfahrungsbasierten Verstehens. [Theory of experience based learning.] In D. Krüger & H. Vogt (Eds.), *Theorien in der biologiedidaktischen Forschung: Ein Handbuch für Lehramtsstudenten und Doktoranden [Theories in biology didatice research: A handbook for student teachers and doctoral students]* (pp. 105–116). Springer.

Groß, J., & Gropengießer, H. (2019). Learning strategies for understanding biological phenomena: The role of embodied schemas and metaphors in teaching. In J. Groß , M. Hammann, P. Schiemann, & J. Zabel (Eds.), *Biologiedidaktische Forschung: Erträge für die Praxis [Didatic research in biology: Income for practice]* (pp. 60–74). Springer. *Income for Practice*. Berlin, Germany: Springer Spektrum. pp. 60-74.

Hampe, B. (2008). Image schemas in cognitive linguistics: Introduction. In J. Groß , M. Hammann, P. Schiemann, & J. Zabel (Eds.), *Biologiedidaktische Forschung: Erträge für die Praxis [Didatic research in biology: Income for practice]* (pp. 60–74). Springer.

Harms, U., & Reiss, M.J., (Eds.) (2019). *Evolution Education Re-considered. Understanding What Works.* Springer.

Heinze, T. (2001). *Qualitative Social Research*. De Gruyter.

Johann, L.I., Rusk, F.K.H., Reiss, M.J., & Groß, J. (2022). Upper secondary students' thinking pathways in cell membrane biology-an evidence-based development and evaluation of learning activities using the model of educational reconstruction. *Journal of Biological Education, Ahead of Print*, 1-22.

Johnson, M. (2008). *From Perception to Meaning: Image Schemas in Cognitive Linguistics*. De Gruyter Mouton.

Kaddoura, M. (2013). Think pair share : A teaching learning strategy to enhance students' critical thinking. *Education Research Quarterly*, 36(4), 3-24.

Kattmann, U., Duit, R., Gropengießer, H., & Komorek, M. (1996). *Educational Reconstruction-bringing Together Issues of Scientific Clarification and Students' Conceptions*. Virginia: Annual Meeting of the National Association of Research in Science Teaching. p. 19.

Kattmann, U., Gropengiesser, H., & Hörsch, C. (2017). *Biologie unterrichten mit Alltagsvorstellungen - Didaktische Rekonstruktion in Unterrichtseinheiten*. *Teaching Biology with Students' Conceptions - Educational Reconstruction in Teaching Units*. Klett Kallmeyer.

Kövecses, Z. (2015). *Where Metaphors Come From*. Oxford University Press.

Krall, R.M., Lott, K.H., & Wymer, C.L. (2009). Inservice elementary and middle school teachers' conceptions of photosynthesis and respiration. *Journal of Science Teacher Education*, 20(1), 41-55.

Lakoff, G. (1990). *Women, Fire, and Dangerous Things: What Categories Reveal about the Mind.* University of Chicago Press.

Lakoff, G., & Johnson, M. (2003). *Metaphors We Live By*. University of Chicago Press.

Lasry, N., Mazur, E., & Watkins, J. (2008). Peer instruction: From harvard to the two-year college. *American Journal of Physics*, 76(11), 1066-1069.

Leach, J., Driver, R., Scott, P., & Wood-Robinson, C. (1996). Children's ideas about ecology 2: Ideas found in children aged 5-16 about the cycling of matter. *International Journal of Science Education*, 18(1), 19-34.

Lyman, F. (1981). The responsive classroom discussion: The inclusion of all students. Retrieve from: https://www.scienceopen.com/document?vid=347f5de1-c4d9-46e9-a869-fc37cf19383b.

Marmaroti, P., & Galanopoulou, D. (2006). Pupils' understanding of photosynthesis: A questionnaire for the simultaneous assessment of all aspects. *International Journal of Science Education*, 28(4), 383-403.

Mayring, P. (2002). *Einführung in Die Qualitative Sozialforschung Introduction to Qualitative Social Research.* (5th ed.). Beltz.

Mayring, P. (2004). Qualitative Content Analysis. In: Flick, U., von Kardorff, E., & Steinke, I., (Eds.), *A Companio to Qualitative Research*. United States: SAGE Publications Inc. pp. 266-269.

Messig, D. (2020). *Fotosynthese Verstehen-entwicklung und Evaluation einer Unterrichtsstruktur unter Anwendung der Metapherntheorie*. *Understanding Photosynthesis-development and Evaluation of a Lesson Structure using Metaphor Theory*. Germany: Carl-Auer-Systeme Verlag.

Messig, D., & Groß, J. (2018). Understanding plant nutrition-the genesis of students' conceptions and the implications for teaching photosynthesis. *Education Sciences*, 8(3), 132.

Munson, B.H. (1994). Ecological misconceptions. *The Journal of Environmental Education*, 25(4), 30-34.

Niebert, K., Marsch, S., & Treagust, D.F. (2012). Understanding needs embodiment: A theory-guided reanalysis of the role of metaphors and analogies in understanding science. *Science Education*, 96(5), 849-877.

Phillips, D.C. (2000). *Constructivism in Education: Opinions and Second Opinions on Controversial Issues*. University of Chicago Press.

Robertson, K. (2006). *Increase Student Interaction with "Think-Pair-Shares" and "Circle Chats."* Available form: https://www.colorincolorado.org/article/increase-student-interaction-think-pair-shares-and-circle-chats

Rohrer, T. (2005). Image schemata in the brain. In B. Hampte (Ed.), *From Perception to Meaning: Image Schemas in Cognitive Linguistics* (pp. 165–198). De Gruyter Mouton.

Stavy, R., Eisen, Y., & Yaakobi, D. (1987). How students aged 13-15 understand photosynthesis. *International Journal of Science Education*, 9(1), 105-115.

Strike, K.A., & Posner, G.J. (1982). Conceptual change and science teaching. *European Journal of Science Education*, 4(3), 231-240.

White, R., & Gunstone, R. (1992). *Probing Understanding*. The Falmer Press.

Zabel, J. (2007). *Stories and Meaning : What STUDENTS' Narratives Reveal about their Understanding of the Theory of Evolution*. January: Conference of the European Science Education Research Association.

Zembylas, M. (2005). Three perspectives on linking the cognitive and the emotional in science learning: Conceptual change, socio-constructivism and poststructuralism. *Studies in Science Education*, 41(1), 91-115.