Articles

The Zoom Map: A New Graphic Organizer to Guide Students' Explanations Across the Levels of Biological Organization

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Abstract

Employing scientific reasoning when giving biological explanations comes easily to the experienced scientist. However, students often encounter difficulty when they attempt to explain biological phenomena. One significant obstacle appears to be the failure or inability to bear in mind the levels of organization. To address this issue, learning strategies, such as the yo-yo learning and teaching strategy, recommend moving across the levels of organization and making those levels explicit in the explanation. To support yo-yo learning, we developed a new graphic organizer, the zoom map. The zoom map combines the levels of organization with concept maps. It is specifically tailored to guide students in biology on ways to distinguish, interrelate and reflect the levels of organization. In this paper, we introduce the zoom map as a tool for instruction and diagnosis. We also provide evidence from teaching experiments that demonstrate how the zoom map benefited learning.

Keywords*:* graphic organizer, concept map, levels of organization, yo-yo learning, systems thinking

Introduction

Employing scientific reasoning when giving biological explanations comes easily to the experienced scientist. However, students often struggle to explain biological phenomena. One significant obstacle is the failure or inability to bear in mind the levels of organization. Research conducted on a wide range of topics has revealed that the levels of organization often present an obstacle to learning in biology (Schneeweiß & Gropengießer, 2019). Confusing the levels (Wilensky & Resnick, 1999), explaining on only one level (Jördens et al., 2016), or failing to interrelate the levels (Brown & Schwartz, 2009) are often at the root of the problem.

To assist teachers, Jördens et al. (2016), and based on previous work by Knippels (2002); Knippels et al. (2005); Verhoeff et al. (2008) adapted the yo-yo learning and teaching strategy. Moving up and down the levels of organization is the underlying principle of yo-yo learning, and this technique has been valuable for structuring learning sequences and guiding teaching processes. Nevertheless, teachers still need to explicitly encourage learners to interact with the levels of organization (Hammann, 2019).

To remedy this shortcoming, we have developed a new graphic organizer, the zoom map. This is a tailor-made tool to guide biology students and help them distinguish, interrelate, and reflect the levels of organization. In the section below, we first explain our understanding of how explanations are constructed. We then describe the starting points for the development of the zoom map, namely the concept map and yo-yo learning. Finally, using case studies taken from our teaching experiments, we explain and discuss the learning opportunities and difficulties presented by the use of the zoom map.

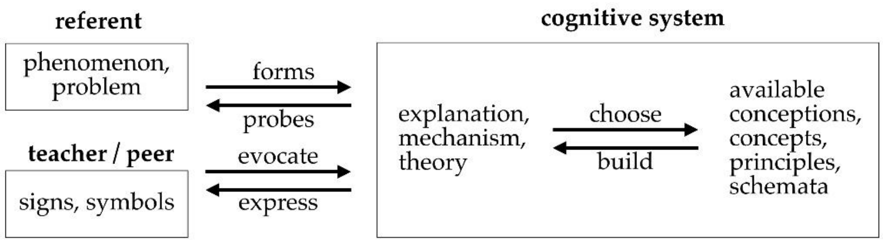
Theoretical Background

2.1 Emergent construction in interaction

Students do not have existing explanations for phenomena already stored in their memory. Instead, students construct such explanations in situations of social learning and through interaction with three sources, two of which are external and one of which is internal. To construct an explanation, an individual interacts with (1) the object of reference (i.e., the

Figure 1.

Emergent construction in interaction.



Emergent construction in interaction (arrows) with a phenomenon, utterances of teacher or peer, and the resources of available cognitive structures.

phenomenon to be explained) (2) other people (i.e., teacher and peers) and (3) with their available cognitive resources (i.e., conceptions, concepts, principles, and schemas) (Figure 1). This process is called "emergent construction in interaction" (Boersma & Geraedts, 2009; Schwarz et al., 2008).

The construction process needs time and may involve trial and error. The result is a temporarily conscious but ephemeral explanation that rests on available stable cognitive structures.

Emergent construction in interaction results in explanations, mechanisms, and theories that usually constitute relatively complex structures. For instance, explanations do not stand alone. From a scientific standpoint, explanations should be interrelated with other kinds of knowledge. The interrelatedness of knowledge is therefore crucial to the quality of explanations (Linn et al., 2006).

2.2 Graphic organizers for knowledge interrelation

Graphic organizers (GOs) are tools that aid students with knowledge interrelation and have proved fruitful in the teaching of science and biology (Davidowitz & Rollnick, 2001). GOs are "visual knowledge representations" (Nesbit & Adesope, 2006) that can be used to "organize and structure information and concepts and promote thinking about relationships between concepts" (Zollman, 2015, p. 4). Concept maps (CMs) are a well-known example (Novak & Cañas, 2006).

GOs can be constructed by both the expert and the student. On the one hand, expert generated GOs may be beneficial for students because such GOs offer a coherent representation of expert knowledge (Robinson & Kiewra, 1995), and they focus on the interrelation of concepts (Hall et al., 1999). On the other hand, recent findings show that GOs constructed by students themselves improved their comprehension skills (National Reading Panel, 2000) and led to the generation of more interrelated ideas (Schwendimann & Linn, 2016).

2.3 Understanding is based on experience

If we assume that GOs help students to structure and interrelate existing knowledge and that knowledge is actively built by the students based on their prior knowledge (von Glaserfeld, 1989), we must ask two crucial questions: How does basic available knowledge emerge in an individual, and how can students acquire new conceptions?

The theory of experientialism (Gropengießer, 2007; Lakoff & Johnson, 1999) suggests an answer: Cognition is embodied. Our basic concepts, principles, and schemata arise from recurrent interactions with the physical and social environment, through perception and experience. Physical experiences induce embodied concepts and schemes that can be understood directly, such as "tree" or "source-path-goal schema" (Niebert et al., 2012). Abstract concepts, such as scientific explanations, mechanisms, and theories, are not understood directly but by imaginative thinking. This process can be described as "understanding through conceptual metaphors" (Gropengießer, 2007; Lakoff & Johnson, 1999). Conceptual metaphors bridge "the gap between experience and abstract phenomena" (Niebert et al., 2012, p. 852).

Teachers should offer opportunities and environments that foster meaningful learning (Ausubel, 1968). To make learning meaningful, interventions should, on the one hand, connect to prior knowledge and, on the other hand, adequately guide the interaction process (Novak & Gowin, 1984) We propose the zoom map as a tool that would help teacher achieve both these goals..

The Zoom Map - A Graphic Organizer to Guide Explanations

The zoom map is based on findings taken from three areas: GOs (particularly CMs,) yo-yo learning, and research on the structure of levels of organization.

3.1 Concept maps

According to Novak and Cañas (2006), a CM can be characterized as follows (Figure 2):

1. A term for one concept is displayed in a box.
2. Lines may connect the boxes, with linking words or phrases (Javonillo & Martin-Dunlop, 2019) in such a way that the terms and linking words can be read as a meaningful statement.
3. The CM is arranged hierarchically: More general concepts should be placed near the top, while more specific concepts should be placed near the bottom.

Based on the theoretical background provided here, we regard the CM as an external representation that expresses the concepts or internal representations of the cognitive system. Terms in a CM denote concepts, statements denote principles, and notions and labels denote relationships.

CMs support meaningful learning by fostering a) externalization (verbalizing and writing concepts as external representations), b) interrelation and c) (re)organization of knowledge (i.e., concepts and prepositions) (Dauer et al., 2013; Fischer et al., 2002; Novak & Gowin, 1984).

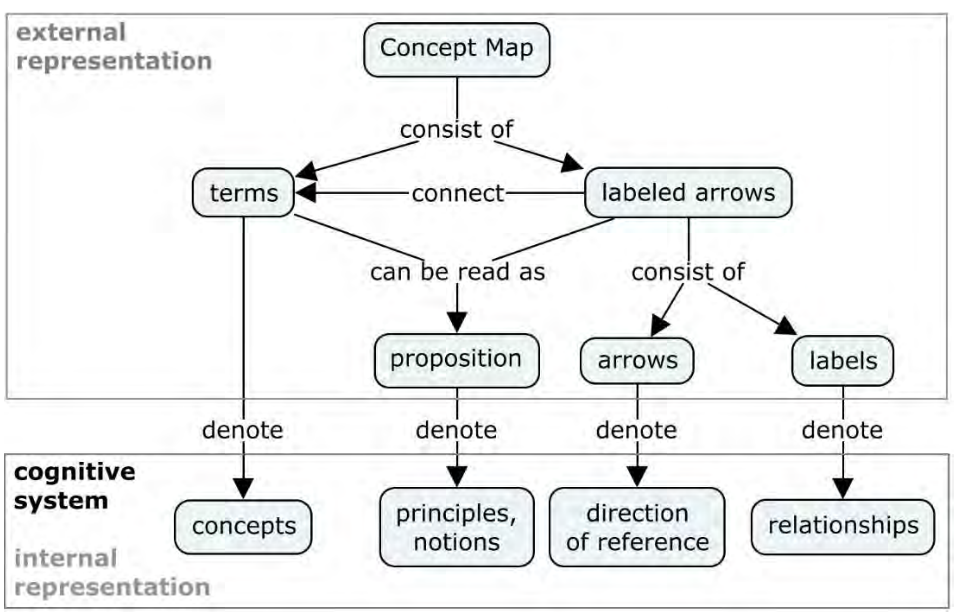
According to Schwartz and Brown (2013), GOs, and especially CMs, can help students connect system levels. The importance of making levels of organization and their relationships explicit was a key insight that we drew from our previous work (Schneeweiß & Gropengießer, 2019). However, existing approaches that used CMs in the context of systems thinking (Brandstädter et al., 2012; Dauer et al., 2013; Schwendimann & Linn, 2016) did not make levels of organization and their relationships explicit.

3.2 Supporting systems thinking with yo-yo learning

The yo-yo strategy builds on the idea of moving up and down the levels of organization – like a yo-yo. The goal of this strategy is to interrelate concepts at the same level (horizontal coherence) and between different levels (vertical coherence) (Hammann, 2019; Jördens et al., 2016; Knippels, 2002).

Figure 2.

Self-referential concept map.



Self-referential concept map (CM) showing its key features.

Our GO, the zoom map, incorporates and supports the steps for teaching systems thinking adapted from Jördens et al. (2016, p. 961). We present the steps with a small deviation. We added an additional step (step 2) in order to identify the components and processes (Tripto et al., 2016, p. 82) before interrelating them. We hypothesize that this will make it easier for students to:

1. Distinguish different levels of organization;
2. Identify the components and processes of a system (and relate them to a level);
3. Interrelate concepts at the same level of organization (horizontal coherence);
4. Interrelate concepts at different levels of organization (vertical coherence);
5. Think back and forth between levels (also called "yo-yo learning")
6. Meta-reflect on the question of which levels have been transected.

3.3 Zooming: A metaphor for levels of organization

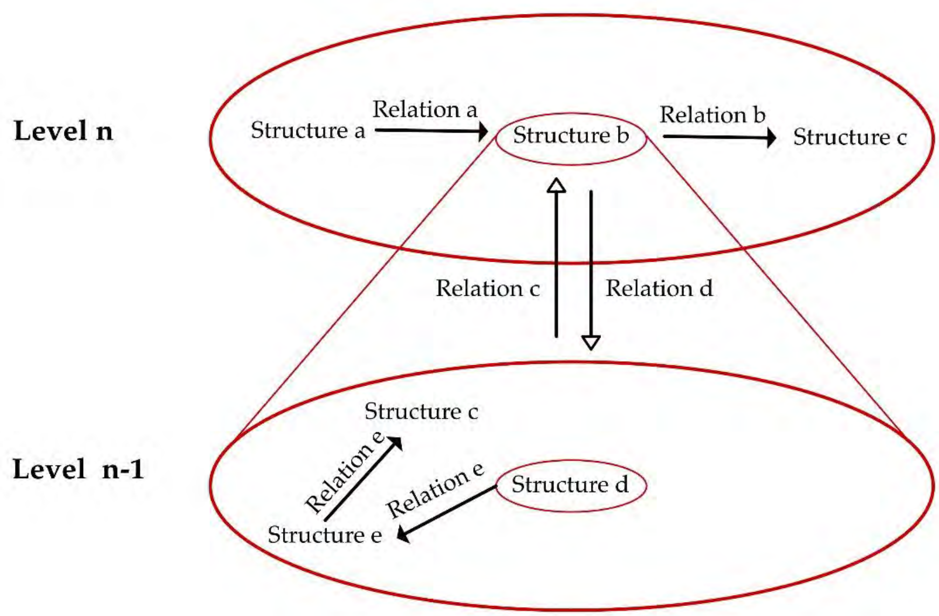
An abstract concept such as the levels of organization cannot be understood directly. To develop our GO, we needed a metaphor for the levels of organization. Although the term "levels of organization" is commonly used in biology, there is no scientific consensus on its description. However, there is consensus about what the levels can do: They can structure scientific problems (Brooks, 2019; Schneeweiß & Gropengießer, 2019). As proposed by Schneeweiß and Gropengießer (2019), based on a critical literature review, zooming is a metaphor for the levels of organization. By zooming in, one focuses on increasingly smaller sections of the problem space without losing sight of the context (Brooks, 2019). By zooming out, one takes the whole, or the context, into account. The metaphor of zooming therefore introduces the notion of structuring scientific problems by focusing on different levels.

Through zooming, we can structure the biological system as consecutive levels of organization, or "zoom levels." The levels are established and connected by different relationships (physiological, coevolutionary, phylogenetical, and matter-energy relationships) that can interrelate the system parts. Depending on the biological phenomenon or research problem being studied, an explanation may require different levels of organization (Schneeweiß & Gropengießer, 2019).

3.4 How to construct a zoom map

We used the metaphor of zooming in and out and combined it with a CM to create a new type of GO, the zoom map (Figure 3).

Figure 3.
Model of a zoom map.



The basic rules for drawing a zoom map were adapted from those that apply to concept mapping (Novak & Cañas, 2006):

1. The levels of organization are displayed as ellipse shapes (Eronen, 2015). By zooming in on a structure at one level, one reaches a lower level. By zooming out, one reaches a higher level.
2. Each ellipse contains the terms for particular concepts.
3. Lines may connect the terms or the levels with linking words. When read together, the linking words and terms should make sense.

The layout of the zoom map can be adapted to the phenomenon that is being taught. However, the explanation that is being sought must involve specific levels of organization. For example, explaining physiological phenomena will require the level of organism and below, while explaining evolutionary phenomena will require the levels above the organism as well, such as the level of population (Schneeweiß & Gropengießer, 2019). In addition, two zoom maps can be juxtaposed. This will be useful when comparing structures and processes in two different organisms, for example.

We will demonstrate and discuss the implementation of zoom maps in the next section.

Our Application of the Zoom Map in Teaching Experiments

4.1 Method

To investigate the potential of the zoom map, we conducted six teaching experiments (A-F). In this variant of a Piagetian interview, the interviewer has two roles: interviewer and teacher (Komorek & Duit, 2007; Steffe & Thompson, 2000). In the first part of the teaching experiment (diagnosis), all the students were interviewed so the interviewer could evaluate how much knowledge the students already had. In the second part (teaching), students were provided with learning material (see 4.2). They worked in dyads in a laboratory setting. Throughout the experiment, students were encouraged to work together and to express their thoughts. No content-related guidance was offered by the interviewer. The focus of the experiments was on the learning opportunities and difficulties that arose from using the zoom map.

Twelve high-school students, with an average age of 16.2 years, participated. All the students and their parents gave informed consent. The interviews were recorded in audio and video and transcribed afterward. We analyzed the transcripts by means of a computer-supported qualitative content analysis (Kuckartz, 2010).

4.2 Material

M1: Two photographs of a variegated nettle, one well-watered and one wilted

M2: A semi-structured zoom map (Figure 5)

M3: Material showing the phenomenon on consecutive zoom levels (photographs)

M4: Material showing the phenomenon on different zoom levels (graphically)

M5: Two models, one with under-inflated and one with fully inflated balloons in connected nets, modelling cells at the level of tissue.

4.3 Schedule of the teaching experiment (Figure 4)

We presented two photographs of a variegated nettle (*Solenostemon scutellarioides*). One photograph shows the plant in a well-watered state, with turgescent, stiff, and erect leaves. The other photograph shows a nettle with wilted and sagging leaves. The students were asked to explain the structural differences between the two states.

Figure 4.

Schedule of the teaching experiment.

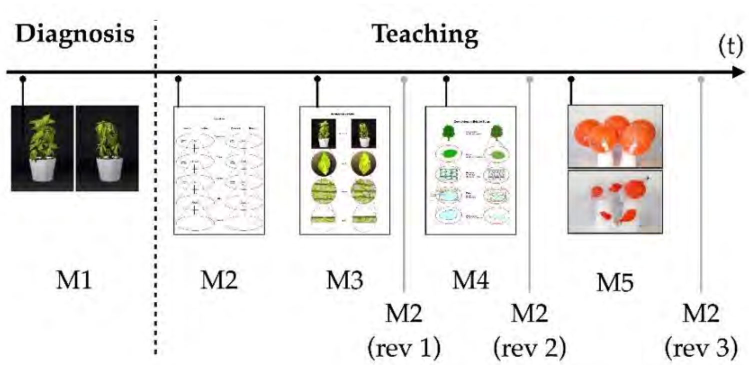
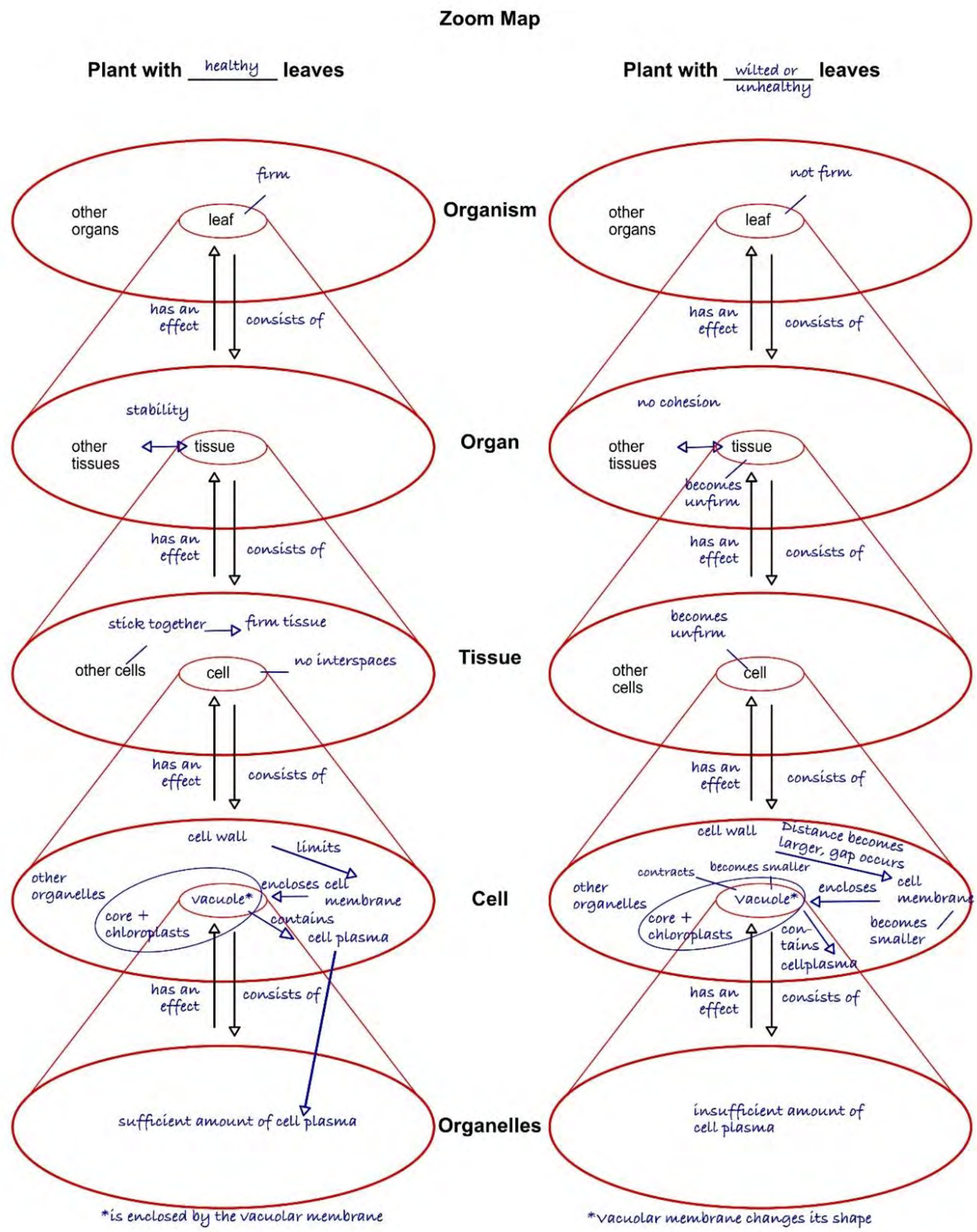


Figure 5.

Examples of student-constructed zoom maps.



Examples of student-constructed zoom maps explaining the difference between a plant with healthy leaves and a plant with wilted leaves. The students' answers are shown in handwriting (teaching experiment C, translated from German to English).

1. Students are asked to describe and explain the phenomenon (M1).
2. Students are asked to use the zoom map (M2) to represent their explanation.
3. Students are asked to describe M3 and revise their zoom map accordingly (rev 1).
4. Students are asked to describe M4 and revise their zoom map accordingly (rev 2).
5. Students are asked to describe and use the models (M5) and revise their zoom map for the final time (rev 3).
6. Students are asked to explain the phenomenon based on their final zoom map.

Results

As educators we are interested in the learning opportunities offered by the zoom map and the difficulties students face when working with this graphic organizer (Figure 5). We are also interested in how students experience the use of this strategy to explain phenomena.

5.1 Learning opportunities

First, although the learning strategies of zoom maps and CMs were new to them, the students were able to construct a zoom map that displayed their understanding of the phenomenon (Figure 5). In their interaction with the zoom map, students (S):

a) identified structures and related them to levels:

Students were able to relate relevant components of the system (plant) to the corresponding level of organization. For example, relations were drawn between the cell wall or cell membrane and the level of the cell (Table 1). Linking system components and linking those components to the levels of organization is one of the first steps in systems thinking.

b) interrelated levels horizontally and vertically (Figure 5):

Based on their own zoom maps, students were able to interrelate structures horizontally and vertically. Horizontal interrelation is the interrelation of notions on the same level of organization, for example, the notion “cell wall —limits—> cell membrane” (Figure 5). An example of the vertical interrelation is the notion “organism —consists of—> organs.”

c) reflected on and discussed the assignment of structures to levels:

S1: Yes, exactly, but you know, we can also make an arrow like that here, [...] because <u>this [vacuole] belongs to the cell</u>, right?”

S2: Yes (teaching experiment E, line 92-93) (Similar in teaching experiment A, line 65-70).

d) Students reflected and discussed horizontal and vertical coherence:

S1: <u>Actually, you could do the arrow the other way around</u>, because the organelle, so to speak, took care of it (teaching experiment D, line 152).

S2: So, what are you writing now?

S1: Internal cell pressure is high or something, and for you it is just small.

Table 1.

Syst*em components that students related to the levels of tissue, cell and organelle in their zoom maps (translated from German.*

Teaching Experiment						
Level						
	A	**B**	**C**	**D**	**E**	**F**
Tissue						Cells
Cell	Cell wall Cell membrane	Cell wall Cell membrane Vacuole Cell plasma	Cell wall Cell membrane Vacuole Cell plasma Chloroplasts core	Cell membrane Vacuole Cell plasma Chloroplasts core	Cell membrane	Cell wall Cell membrane Vacuole Cell plasma Chloroplasts core
Organelle	Liquid	Water	Cell plasma	Water	Cell membrane Vacuole	water

S2: Yeah, okay.

S1: <u>And that has an effect on the tissue, right?</u>

S2: Yes (teaching experiment E, line 95-99)

(Similar in teaching experiment F, line 149-152)

5.2 Students' perception of the zoom map

The students understood the benefit of the zoom map:

S2: Yes, to be able to understand a phenomenon much better […] by proceeding in much smaller steps. You simply write down your thoughts and what you see and then simply continue working.

S1: […] You create things for yourself. In school you learn how things are and now S2 and I have explained this to ourselves in small steps. That's not always the case at school. Normally, we just know that something exists or is dependent on it, but not exactly why. And now we actually know quite well that really every smallest molecule (/)

S2: (/) has an impact on something bigger (teaching experiment D, line 332-333).

5.3 Learning difficulties

Despite the benefits of the zoom map, students struggled with it at first. One challenge was the assignment of structures to the levels.

S1: If you don't have much to do with biology anyway. (/) So, we first had to clarify what a vacuole is. You could already see from the arrows that something is dependent on each other or has an effect on each other. But if you don't know what a cell is made of, or a vacuole, then you don't have an idea (teaching experiment D, line 284).

Moreover, some students did not follow the rules for the construction of a zoom map. Their maps partly resembled mind maps and terms remained unconnected (Figure 6)

Discussion

Biology students struggle with the levels of organization. One of the ways in which teachers can deal with this issue is to use the principles of yo-yo learning. The explicit reflection of and reference to the levels of organization is a defining characteristic of yo-yo learning. We propose the zoom map as a new graphic organizer to guide students across the levels of organization. The zoom map supports the construction of explanations according to the principles of yo-yo learning in the following ways:

By distinguishing different levels of organization

The zoom map depicts the various levels as wide, stacked ellipse shapes. Figure 5 illustrates the levels from organism to cell organelle (In the case of other phenomena, different levels would be depicted).

1. By identifying the components and processes of a system (and relating them to a level)

System elements can be assigned to a system level by writing them into the ellipse shapes. In Figure 5, the cell membrane and the cell wall are assigned to the level of cell.

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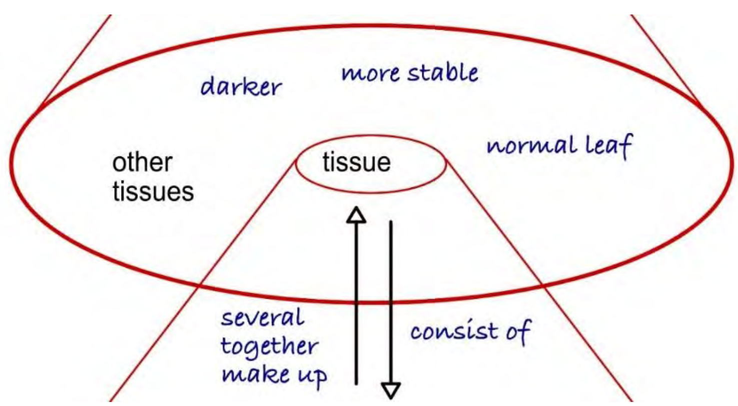
Figure 6.

Zoom map of students form teaching experiment B.



Students of teaching experiment B did not interrelate terms in their zoom map (The students' answers are shown as handwriting).

2. By linking concepts that are at the same level of organization (horizontal coherence)

The system elements are linked by words or phrases that form propositions when the reading direction indicated by the arrows is followed. The rules for the construction of CMs apply. Propositions should be meaningful.

3. By linking concepts at different levels of organization (vertical coherence)

The user of the zoom map can zoom in on each structure and then describe the system at a lower level (n – 1), for instance, when zooming from the level of tissue to that of cell. On the level of the cell, the user can again assign and link system elements. The different levels can be related vertically.

4. By thinking back and forth between levels (yo-yo learning)

When trying to explain a phenomenon, students should start at the level of that phenomenon. Usually, this is a level that is within the range of perception, like the level of organ, organism, or population. With the help of supporting material, students can move downwards and explore each level, repeating steps 1 to 4. Finally, based on their zoom map, they can try to give causal explanations of the phenomenon or identify missing knowledge. This step usually involves moving upwards in the zoom map.

5. By allowing for meta-reflection on the question "which levels have been transected?"

Moving across levels and reflecting those levels are inherent to the construction of a zoom map. The first indication of a level occurs when system elements are assigned to levels. The second indication of a level concerns the horizontal and vertical interrelations. In the construction process, students have to make choices. Comparing individual zoom maps can further support learning. The teacher should give feedback and guide the discussion as needed.

Some of the students who participated in our teaching experiments struggled to work with the zoom map. This might be due to their lack of experience with the levels of organization, especially levels lower than "organ." This does not mean that these students will not be able to learn using this method. Teachers or peers can encourage struggling students to reconsider unrelated terms. If the student can make no further connection, missing interrelations may indicate subject areas that the student has not mastered yet.

It is important to note that the zoom map can only support the construction of ideas and notions on a phenomenon. To enable the construction of adequate concepts, students need additional material (e.g., photographs, experiments) that offer the necessary experience of the phenomenon and to further denote conceptions (Niebert et al., 2012). Even in a zoom map, students will not be able to link concepts that they have not yet constructed in their minds. Depending on the needs of the students, different levels of scaffolding are possible.

The expert zoom map is the simplest form. Constructed by the teacher, the map guides the students during instruction or serves as a comparison with a student-constructed zoom map. Semi-structured maps are an accessible introduction to zoom maps (Figure 5). Students are asked to complete zoom maps that have been partly filled out. The semi-structured map supports the construction process by making it easier to relate structures to the levels of organization.

Students who are familiar with the principles of the zoom map can work with empty maps that depict the levels only. Eventually, advanced students can construct their own zoom maps by deciding which levels are needed to explain the phenomenon in question.

Like CMs, zoom maps can be used as a diagnostic tool. A completed zoom map expresses a student's conceptual framework across the levels of organization. The zoom map will reveal not only the learning gains that have been made but also any remaining issues related to levels of organization, for example, when interrelations are missing or there is slippage between levels.

Conclusion

The zoom map can be a valuable tool in the teaching and learning of biology. When students interact with a zoom map, its inherent structure allows them to construct explanations that span multiple levels. The zoom map therefore guides students across the levels of biological organization and offers starting points for horizontal and vertical coherence. Like CMs, the zoom map is a learning strategy – as such, it has to be learned (Sumfleth et al., 2010). It is therefore advisable to support students by offering different scaffolds, such as semi-constructed zoom maps or expert maps, until they understand the principles involved.

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