ARTIGOS TEMÁTICOS

THE MODELLING IN DEVELOPMENTAL EDUCATION: A CONDITION FOR THEORETICAL ABSTRACTION AND GENERALIZATION *

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Abstract: *The aim of the study is to explore how the modelling, as a condition for theoretical abstraction and generalization, takes shape in a certain sequence of a biology instruction based on the El'konin-Davydov Program. Research questions are: How are the students' diagrams handled in the modelling process? What is the character and the function of the teacher's questions and actions during the modelling process? The data consists of teachers' lesson plans and fieldnotes related to a certain modelling carried out in several classes. Based on the results of the analysis we conclude that the students' diagrams are used as means of the collective process of abstraction towards the generalized model. The teacher organizes and leads the modelling process so that theoretical abstraction becomes possible; thus, the students discern the general in the specific case and begin developing a theoretical concept.*

Keywords: *Modelling. Concept formation. Theoretical concept. Abstraction. Generalization.*

According to the cultural-historical tradition, formal instruction plays a key role in students' cognitive development; specially organized instruction enables acquisition of culturally evolved cognitive tools – *concepts*, historically mastered by mankind. The quality of instruction in terms

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of its content has a decisive influence on the opportunities created for the development of students' thinking (ARIEVITCH, 2017; CHUDINOVA, 2019a; DAVYDOV, 1990; 2008; EL'KONIN, 1989; EL'KONIN, 2020; HEDEGAARD; CHAIKLIN, 2005; VYGOTSKII, 1987; ZUCKERMAN *et al*., 1998, etc.). In discussing methods and content of the formal instruction and its developmental effects, Davydov (2008) highlights the importance of distinguishing two different kinds of concepts — empirical and theoretical. He states that the traditional approach is oriented towards developing empirical concepts and thus "cannot be effective in forming in the students a basically creative attitude toward the science" (DAVYDOV, 1988, p.178). According to Davydov, the main task of the educational system is to enable acquisition of theoretical concepts and thus, make possible for the students to develop theoretical thought. Acquisition of theoretical knowledge[1] requires an educational process, organized as a *learning activity, consisting of learning actions* (DAVYDOV, 1990; 2008; EL'KONIN, 1989). One of these actions – the learning action of modelling – is crucial for enabling content (theoretical) abstraction and generalization, and thus for developing a theoretical concept. How the modelling as a condition for contentful (theoretical) abstraction and generalization *takes shape in the instruction* is therefore of interest for teachers and researchers.

BACKGROUND

DEVELOPING STUDENTS' THINKING: FROM THE EMPIRICAL TO THE THEORETICAL ABSTRACTION AND GENERALIZATION

The formation of an empirical concept as well as the formation of a theoretical concept embraces two kinds of logical operations: abstraction and generalization (DAVYDOV, 2008). How then do empirical and theoretical concepts differ in the nature of the logical operations to which they correspond? The work of thought that corresponds to an empirical abstraction and empirical generalization is of a different kind than the work of thought that corresponds to a theoretical abstraction and theoretical generalization. Empirical abstraction means distinguishing by direct experience a certain quality of an object from the object's other qualities. Generalizing empirically means identifying this certain quality as common for a group of objects. These two operations of abstraction and generalization are inseparable from each other: "Delineating a certain quality as a common one includes separating it from other qualities'' (DAVYDOV, 1990, p. 6). The empirical generalization is a result of *comparison and classification*. If a student gives a word a meaning that reflects an empirical abstraction and generalization, then one can say that the student has developed an empirical concept as a tool of his/her mind (ZUCKERMAN, 2018).

Theoretical abstraction requires *analysis* of the object in order to understand how the studied object is constituted (arises/ is created). That is, the focus is on the *essence* of the object studied. The theoretical abstraction is therefore of a different nature than empirical abstraction. Theoretical abstraction is not possible through direct experience of the object's various characteristics and properties, it implies exploratory, transformative work so that the object's constituent relations – its essence – emerge. To generalize on a theoretical basis means tracing the interconnections between the revealed essence and particular phenomena (DAVYDOV, 2008, p. 105). "Generalization is regarded, as a rule, as inseparably linked to the operation of abstracting", according to Davydov (1990, p. 6). These individual phenomena including the examined object, then appear as particular manifestations of one and the same general relation.

If the meaning the student put into a certain word corresponds to a theoretical generalization, one can say that the student has developed a theoretical concept as a tool of his/her mind. In the following section two examples are presented to clarify the reasoning.

The Concept of "Circle"

Through observation and comparison of different circles the student identifies: a) the circular form as a specific property of the item; b) the circular form as a common visible property for a group of items. Thereby the student does/performs a) an empirical abstraction and b) an empirical generalization of the *circle*. Empirical generalization is made possible through working with a set of examples, where the attention of the student is directed to the properties which these examples have in common and which are possible to *directly experience*. On the basis of empirical generalization, it is possible for the student to draw/create a circle-like figure by imitating the circular shape. The student can probably also distinguish a *circle* from a *non-circle*. Starting from a *circle* as an empirical generalization, the student can thus solve a certain kind of task. Thus, when empirical generalization is the goal, it is distinctive for the work that the student observes the objects and makes various comparisons in order to classify them (DAVYDOV, 1990, p. 140).

In order to make a) a theoretical abstraction and b) a theoretical generalization of a circle the student has to distinguish a) what constitutes *this particular* circle and b) at the same time *any* circle *in general.* What constitutes each circle is the general relation between a given point - the center of the circle - and all points in a plane that are equidistant from this given point.

Each circle has a radius, but the radius can be of different lengths. The circle is constructed by a movement, in the plane, of the radius as a line – with one of the end points attached. As Davydov says, the essence of a circle is perceived "in the act of its emergence or construction" (DAVYDOV, 1990, p. 117). This corresponds to the general way (DAVYDOV, 2008, p. 124) of circle construction: "Here a method of obtaining any and infinitely varied circles is given" (DAVYDOV, 1990, p. 117). The theoretical generalization is made possible by the fact that the general relations and the general approach to constructing a circle constitute the object of the student's thinking. On the basis of the theoretical generalization, it is possible for the student to construct a perfect circle. The student's development of the circle as a theoretical concept already when in the lower grades, enables a progression in his/her mathematical thinking later on.

The Concept of "Day and Night"

Through observations, the student can - if it is not cloudy - directly experience how the sun goes up and down and that it becomes light and then dark. Thereby the student does/performs an empirical abstraction, thus the student distinguishes a shift between light and darkness as characteristic of the observed process. The student can also observe that light and darkness - day and night - change repeatedly. Accordingly, the expression *day and night* gets the meaning of a time interval which comprises such a shift and which can be clocked to 24 hours. Thereby, an empirical generalization is made possible, that is, the student discerns that the shift is repeated and thereby develops *day and night* as an empirical concept. The empirical generalization may therefore be made possible through working with a set of examples, here a number of observations, and the properties which these examples have in common are the object of the student's thinking. To enable a theoretical abstraction of *day and night* (of the Earth), the student needs to discern what constitutes *day and night*, i.e., how *day and night* arises. What constitutes the Earth's *day and night* is the general relation between the sun (the star), the movement of the Earth (the planet) around its own axis and the observer position on the ground. To make a theoretical generalization, the student needs to discern this general relationship between the star, the planet's motion around its own axis and the observer's position as characteristic for any *day and night. Day and night* is manifested differently depending on the position of the observer, which planet and which star is in focus - a *day and night* can vary regarding length of time, regarding time distribution between day and night, etc. The relationships between the sun, the earth's movement around its axis, and the observer's position are not possible to distinguish from the students' position on Earth. Davydov (1990) points out that

> *internal, essential relationships cannot be observed directly by the senses, since they are not given in available, established, resultative, and dissociated being. The internal is detected in mediations, in a system, within a whole, in its emergence (DAVYDOV, 1990, p. 255).*

To discern these relationships, and thereby develop a theoretical concept of *day and night*, the students need to engage in a certain kind of work. A theoretical abstraction and generalization of *day and night* - i.e., the development of *day and night* as a theoretical concept - becomes possible when the general relations constitute the object for the students' thinking.

The teacher's role in developing of students' thinking: modelling as a means of the theoretical abstraction and generalization

The teacher-students joint activity needs to be of such a nature that it enables the students to discern the *general*, which constitutes the studied object. Such a discernment is necessary for students to master a certain generalized method of action – “modus operandi”. In the teaching example, which is analyzed in the present article, the subject content is represented by a certain biological concept. Biological concepts are significantly different from mathematical concepts for example, or concepts within social sciences. Every theoretical concept within biology captures a certain *modus operandi* that living creatures have at some point developed to solve the problems caused by nature. It is the biologists’ interest in understanding such problem solving that has led to developing subject-specific biological concepts. As discussed above, the theoretical abstraction implies studying of the object through its transformation so that the general would come into sight. Why is this of importance? When the students encounter new subject matter, what is possible to experience directly is what becomes the focus of their attention and thus, is what is recognized. Therefore, in order for the students to abstract theoretically, the instruction needs to allow for a shifting to the foreground what constitutes the object of study – the general. In order to bring the essential to the fore, and at the same time put the non-essential in the background, a certain work is needed: modelling (DAVYDOV, 1990). Modelling is a process that aims to abstract and make visible only the general in the object:

> *Models are a form of scientific abstraction of a particular kind, in which the essential relationships of an object which are delineated are reinforced in visually perceptible and represented connections and relationships of material or symbolic elements. This is a distinctive unity of the individual and the general, in which the features of a general, essential nature come into the foreground (DAVYDOV, 1990, p.122).*

Thus, through modelling, the general relations of the object become possible for students to discern. A mathematical formula, students’ movements - for example imitating the shift between day and night - a construction drawing for building, etc. are examples of how signs, movements, diagrams and drawings can serve as models of what is being investigated. The term “model” is used here to denote a function of the object - not a property. Something has the function of a model when it is used by someone as a tool in exploratory thinking. A three-dimensional miniature of the solar system certainly does not have the function of a model for a three-year-old, rather possibly the function of a fun toy. On the other hand, the three-dimensional miniature of the solar system may have the function precisely of a model for the student who uses it to investigate the movements of the planets in relation to each other. Chudinova and Gorbov (2000) show that models and modelling have various functions in instruction. Two of these functions are particularly important for our analysis: making visible to oneself and to others one's own investigative action and fixing the general relations discovered in studied objects (CHUDINOVA; GORBOV, 2000). The modelling itself can be performed in many different ways. For example, by working with a diagram, working with a material construction, or even by using one's own body.

Overall, it can be said that the process of modelling implies that the students together with the teacher a) gradually construct a model of the studied object, i.e., make a theoretical abstraction of the relation(s), which underlie the studied object; b) test the possibilities and limitations of the model and adapt it so that it becomes general, namely works for a whole class of objects. By constructing the model step by step, the students explore general relations without them being "overshadowed" by other aspects (DAVYDOV, 1996, p. 161-162). Then, one might ask: how does the theoretical abstraction and theoretical generalization take shape in the classroom?

Aim of the Study

The aim of the present study is to explore how the modelling, as a condition for theoretical abstraction and generalization, takes shape in a certain sequence of a biology instruction based on the El'konin-Davydov program. The following research questions are formulated:

– How are the students' diagrams used in the modelling?

– What is the character and function of the teacher's questions and actions in the modelling?

DATA AND METHOD

Data

The data relates to a specific modelling situation in biology teaching in year 8 (CHUDINOVA, 2019a; 2019b). This specific modelling situation constitutes the object of analysis. The lesson, during which the intended modelling was carried out, was initially planned and organized in collaboration between the researchers and some teachers. During the years 2010-2020 approximately 40 lessons, all based on the same certain lesson plan, were conducted by different teachers at several schools located in cities as well as in rural Russia. However, all teachers did not participate in the very initial planning of the lesson, but they were all well initiated sharing with the researchers the understanding of the aim of the lesson and the modelling. The data consists of the initial plan for the certain, the teachers' field notes (based on their own completed lessons and their own film recordings of the lesson) and the researchers' film recordings of the lesson from two of the schools – school 91 and school 67[2]. All written data was anonymized when the analysis began. The teachers have consented to share their field notes and lesson plans with the research group. The students, who were involved in the researchers' film recordings, have consented to the use of the films for research purposes.

METHOD

The aim of the study was to explore how the modelling, as a condition for theoretical abstraction and generalization, takes shape in a certain sequence of a biology instruction based on the El'konin-Davydov Program.

Through an analysis of the certain modelling in the teacher-student interaction, we intended to identify the process of abstraction and generalization, described by Davydov (1990). First, the larger amount of data, consisting of the teachers' lesson plans and fieldnotes regarding the certain lesson, was examined in order to "extract" a sequence of teacher-student interaction that the teachers as well as the researchers considered to be representative of the certain modelling as it is usually manifested in the teaching. This extracted modelling is the object of microanalysis in this study, and in the following it is referred to as the "teaching example". In the teaching example, students are involved in this modelling during a lesson within a biology course in school year 8. The lesson was developed and tried out by the Moscow research group in collaboration with several schools.

In the biology course the students have recently completed a theme on living creatures[3] and their construction, and on the function of various systems in the body. Living creatures appeared to the students in terms of living mechanisms functioning in a certain way, not changing while we study them. The teaching example, referred to in this article, directs the students' attention to the living creature as a creature developing over time, as well as a creature reproducing. Thus, the instruction concerns reproduction and the individual development of living creatures and enables the students to begin developing the *life cycle* as a theoretical concept. This concept serves as an entrance to developing the concepts *genetic information*, *genes*, *mitosis* and *meiosis* – other key concepts which students are supposed to master during the continuation of the biology course.

In present study, the teachers' field notes, based on their own completed lessons and film recordings, and researchers' film recordings of the lesson carried out in school 91 and school 67 have been used to reconstruct and exemplify the "best practice" modelling sequence. Points of departure are the understanding of a) the modelling as a joint teacher–students' activity with certain characteristics and b) the students' current version of the diagram as reflecting their current thinking on the issue. Thus, to explore how students' ways of thinking are adjusted during the modelling, we direct the analytical focus towards the very nature of the different versions of the students' diagrams. Moreover, in the analysis the teacher's questions in the joint modelling serve as an entrance to the exploration of how the students are enabled to successively adjust and develop their thinking on the issue. The rows and columns in Table 1 in the results section reflect this analytical entrance.

RESULTS

The interaction between the teacher and the students during the lesson is described, exemplified and analyzed below. The joint work of the teacher and the students during step 6 is the object of the microanalysis. Step 6 is, therefore, described in detail in tabular form. The detailed description reflects important elements of the teacher-students interaction and thus reveals the interaction's function in the ongoing modelling.

- Step 1. The work starts with the students reading a text about the development of a mayfly, see below (didactic text prepared by the authors):

Mayflies are aquatic insects, a part of an ancient group of insects termed the Palaeoptera, which also contains dragonflies. Over 3000 species of mayfly are known worldwide.

Adult mayflies, or imagos, are delicate-looking insects, they are relatively primitive in structure. They have long tails and wings as the first flying insects.

For a day or two in the spring or autumn, one can see mayflies everywhere, they are dancing around each other in large groups - swarms. They fly a few meters above water with clear open sky above it, and perform a courtship dance. Each insect has an up-and-down pattern of movement. Mating takes place in the air. The primary function of the imago is reproduction; adults do not eat and have non-functional mouthparts.

Females usually lay between 400 and 3000 eggs. The eggs are often dropped onto the surface of the water. When the eggs hatch, the nymphs emerge. Nymphs live primarily in streams under rocks, they eat and grow. Moults are more numerous in mayflies than in most other insect orders: between 10 and 50. The nymphal stage of mayflies may last from several months to several years. The brief lives of mayfly adults have been noted by naturalists and encyclopedists since Aristotle: the adult females of some species live for less than several minutes.

After the reading the students are asked to answer some questions from the teacher. The students discuss in pairs or in small groups: "Can it be said that mayflies, mayfly nymph and mayfly eggs look different?", "Is the duration of the respective stages the same?" and "Is the way to live and to function the same in all stages?"

The questions above aim to direct the students' attention to how different stages are described in the text. In order to answer the questions, the students need to retrieve the necessary information from the text and to analyze it.

- Step 2. The teacher initiates the discussion. The students are given the opportunity to compare and discuss different answers. The teacher provides the students with some images (see figure 1) in order to support the discussion. The images illustrate the three stages in the development of a mayfly: an adult mayfly (1a), a mayfly egg (1b) and a mayfly nymph (1c). The teacher's mission is to direct the students' attention to the content of the text so that everything the students claim is supported by the text.

1a 1b 1c

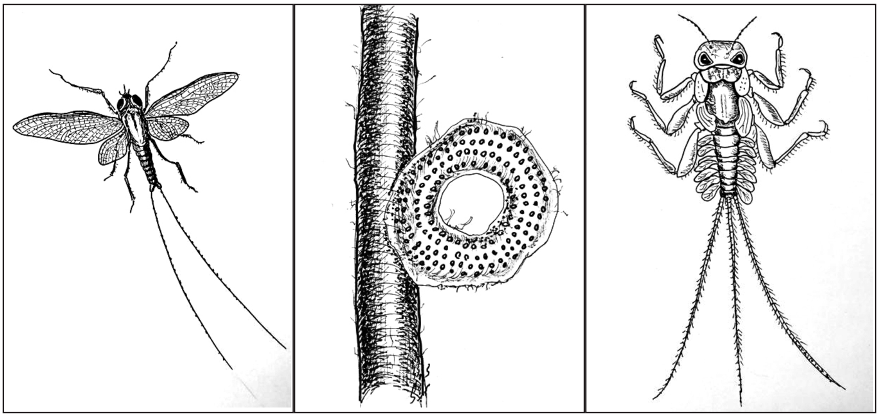


Figure 1: Developmental stages of a mayfly, from left to right: 1a. Adult mayfly (imago), 1b. Mayfly egg, 1c. Mayfly nymph

Source: own elaboration. Illustration by the CHUDINOVA

- Step 3. The students get a new question from the teacher. The teacher encourages the students to substantiate their answers using the text. The question is: "Does the mayfly in the different developmental stages have the same construction for living?".

Here, the answers may vary. Most students answer that in the different developmental stages, the mayfly is designed differently to be able to live. If any student comes up with a "no" as the answer to the question, the teacher draws the students' attention to the previous teaching content.

- Step 4. The teacher gives an instruction: "Make a diagram, which shows the transitions between the different stages in the development of the mayfly". The teacher asks: "How can we show in the diagram that it is one and the same creature?"

The students work in pairs or in small groups again, creating a diagram. When they are done, they draw their diagram on the whiteboard. Finally, various types of diagrams that the groups have created are represented on the whiteboard.

- Step 5. The teacher encourages the students to read out loud each diagram on the whiteboard. The students who constructed the diagram listen to the other students' interpretation of what the diagram shows. If the authors of the diagram do not agree with the interpretation presented, they correct the diagram so that it represents the initial idea.
- Step 6. The teacher initiates a joint work on the diagrams, which can be followed in table 1, column 1. In column 2, a detailed description of the course of the work is presented. Column 3 presents a step-by-step microanalysis of the teacher's and the students' joint modelling.

Tableau 1: Microanalysis of the teacher's and the students' joint work during step 6

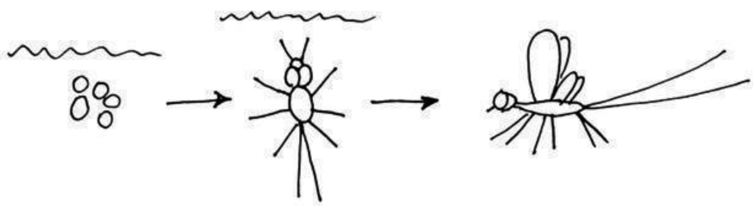
Diagram discussed	
 Diagram 1	
The joint work of the teacher and the students	**Microanalysis**
T(Teacher): Let's read the diagram together! **S(Students):** From a mayfly egg, a mayfly nymph hatches, a mayfly nymph becomes an adult mayfly. **T:** What does the arrow in the diagram mean? **S:** Change, transition. **T:** Is this diagram (1) only on mayflies? **S:** Yes, it is only on mayflies. **T:** Do you want to show that these three variants look different? How can you show it in a simpler way than drawing them?	The teacher starts by directing the students' focus towards the most non-general diagram (see diagram 1).

Diagram 2

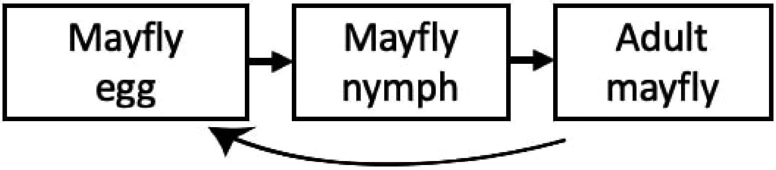


Diagram 3

T: What are the differences between this diagram (2) and the previous one (1)? **S:** No difference, here are words and in the other there are pictures. **T:** We read the diagram (2) together! **S:** From a mayfly's egg, a mayfly nymph hatches, a mayfly nymph becomes an adult mayfly. After that it lays eggs, then everything repeats again and again. **T:** Can you see everything you said now here in the diagram (2)? **S:** No, we add it to the diagram (see diagram 3).	Sometimes the students read something that is not in the diagram. If this is the case, the teacher asks a counter-question to direct the students' attention to what is actually in the diagram. The students then realize that what they read does not correspond exactly to what is in the diagram. As a consequence, diagram (2) is adjusted on the board, usually by a student or the teacher drawing an arrow (see diagram 3).

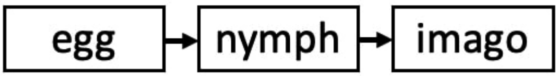


Diagram 4

T: What are the differences between this diagram (4) and the previous one (2)? **S:** There is no difference. **T:** Is this diagram on the mayflies only? **S:** No. It might also be used for frogs or flies. **T:** Are we interested in making a diagram for mayflies only or do we want to make a diagram that can accommodate other animals as well that we see working in the same way as the mayfly? **S:** Yes, we are interested in it being suitable for all animals that function as the mayfly. **T:** Can thus the last diagram (4) be better for us than the previous one?	It may be difficult for the students to see the difference between diagram 4 and diagram 2. The teacher's mission is to make it clear that the latter diagram (4) is more general than the previous one (2) and may therefore apply to other species, not only the mayfly.

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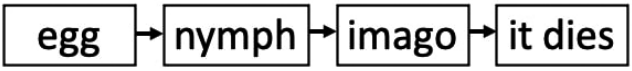
<tr><td colspan="2">

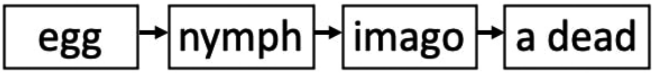
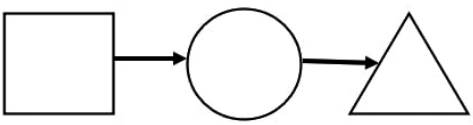
Diagram 5</td></tr>
<tr><th>The joint work of the teacher and the students</th><th>Microanalysis</th></tr>
<tr><td>T: Let's read this diagram (5) together!
S: Egg becomes nymph, becomes imago and it dies.
T: What is the difference between these two diagrams (4 & 5)?
S: This diagram (5) shows the fact that it dies.</td><td>Then the students pay attention to the difference between these diagrams. They notice that diagram 5 is more precise because it also shows that the imago dies.</td></tr>
<tr><td colspan="2">

Diagram 6</td></tr>
<tr><td>T: Let's read this diagram (6) together!
All students: egg becomes nymph, becomes imago, and becomes "a dead".
T: What is the difference between these two diagrams (5 & 6)?
S: They are the same, aren't they?
T: No, do you see that "it dies" is not an object like the other three? It is a process. Objects – egg, nymph, imago – are now in different "boxes". How do we show processes in the diagram?
A: Yes... With arrows. We'll fix that.</td><td>The teacher draws the students' attention to the fact that there is a difference between what is written in the last box of diagram 5 and in the last box of diagram 6. "It dies" corresponds to a process while "a dead", egg, nymph and imago correspond to an object.</td></tr>
<tr><td>
Diagram 7</td><td>
</td></tr>
<tr><td>T: What can you say about this diagram (7)? What is the difference between these two diagrams (7 & 6)?
S: It (7) suits many, but "a dead" is not included. Moreover, the diagram does not show that everything is repeated.</td><td>Most students now read the diagram with more confidence than before. They notice that the diagram is suitable for other animals that function in the same way as the mayfly. They also pay attention to all the small but important details on the diagram, such as what the arrow corresponds to and what the different geometric shapes are</td></tr>
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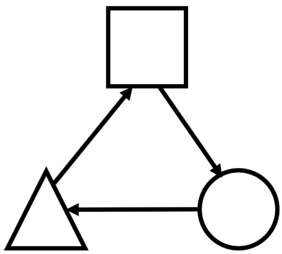
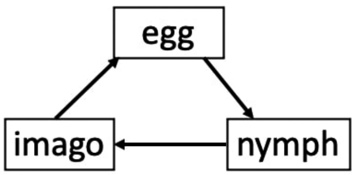
<table>
<tr><td></td><td>intended to show. They notice quite quickly what is missing in the diagram. When introducing signs and shapes in diagrams, the students are asked to write a legend so that everyone can see what the signs and shapes mean. The students write on the board the legends corresponding to their diagrams.</td></tr>
<tr><td colspan="2">
Diagram 8</td></tr>
<tr><td colspan="2">
Diagram 9</td></tr>
<tr><td>T: Read, what do these diagrams show (8 & 9)? Do you remember what the arrows mean?
S: Egg turns into nymph, nymph turns into imago, imago...turns...into egg! (The students usually laugh). Oops, that's wrong.
T: How can we adjust then?
S: We need to have another kind of arrow to show that the imago lays eggs, not becomes eggs.
T: What else is missing in the diagram, if you compare it with this diagram (6)?
S: "A dead".</td><td>The students notice errors when they together read out loud the diagram.
These two diagrams differ regarding the ways of visualization: with the words (Diagram 9) and with the symbols (Diagram 8). Both diagrams are though the same generalized and suits for other animals, not only for the mayfly.</td></tr>
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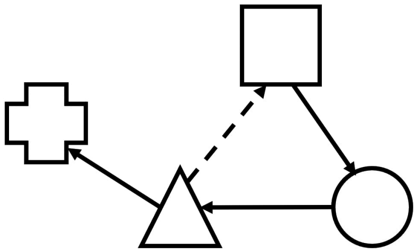

Diagram 10

T: Read, what does this diagram show? **S:** Egg becomes nymph, nymph becomes adult, adult lays eggs and then becomes "a dead". And then it all repeats again. **T:** Let me read out your diagram. The egg of the mayfly turns into the nymph of the fly and becomes a penguin. Then it lays eggs and becomes a donkey. (The students usually laugh). Maybe we need to show in the diagram that it is the same species all the time. How can we do that?	This diagram is not initially among the diagrams drawn by the students on the board, but is created through the joint work on the previous diagram. The teacher invites the students who are not really following along to read out loud what this diagram shows.

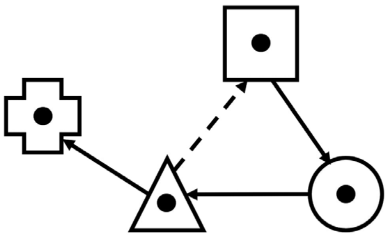

Diagram 11

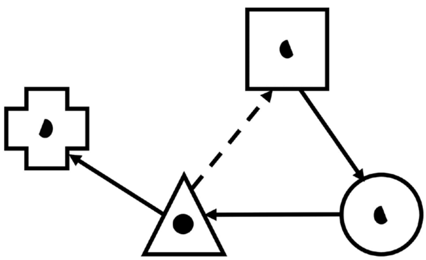

Diagram 12

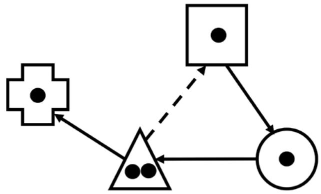

Diagram 13

T: What happens to the "mayflyness" when the mayfly lays eggs and becomes "a dead"? Which mathematical operation is appropriate – multiplication or division? **S:** Multiplication! Division! (Most students answer "division"). **T**: Division. Then the "mayflyness" is divided into two parts. Half goes to the egg and half stays in "a dead". How much "mayflyness" will be left in the next generation? And in the next? And in the next? (Diagram 12) **S:** It gets smaller and smaller... Then it must be multiplication! (Diagram 13) **T:** How does it work then? We'll continue to work on that in the next lesson.	The students come up with the word "mayflyness" which they then use until they get the correct scientific word. The students then demonstrate in different ways that "mayflyness" exists in each stage. Some put dots/crosses in all the boxes, some color all the boxes with one color or write the same letter in each box.

Source: own elaboration.

DISCUSSION

The aim of the study is to explore how the modelling as a condition for theoretical abstraction and generalization takes shape in a certain sequence of a biology instruction, based on the Elkonin-Davydov program.

In the following, the two research questions are discussed:

– How are the students' diagrams used in the modelling?

– What is the character and function of the teacher's questions and actions in the modelling?

THE FUNCTION OF STUDENTS' DIAGRAMS IN THE JOINT ACTIVITY OF MODELLING

The function of the modelling is to enable students to abstract theoretically and discern the essence of the object studied (DAVYDOV, 1990).

The modelling process in the teaching example aims to enable students to make a theoretical abstraction using students' diagrams as a mediating tool (ELKONIN, 2016). The students' diagrams (the diagram on the mayfly's life cycle and transition of the "mayflyness"), play a crucial role in this process. The students' actual thinking is 'visualized' and thus becomes the shared object for discussion (CHUDINOVA; GORBOV, 2000). Through the collective work with the diagrams, students are able to discern what underlies *life cycle*. Furthermore, using diagrams 10-13, students can ask themselves how and where duplication and transmission of "mayflyness" ("genetic information") occurs. These questions are the starting point for further work in the biology course. All versions of the diagrams created by the students during the modelling process are discussed, cleaned, gradually changed and finally end up in a common version agreed by all students. This version is a product of the students' and the teacher's joint work and at the same time it corresponds to the predefined diagram from which the teacher's actions and questions were based. It is important to emphasize that although the teacher owns the general model (here: the general diagram), the model appears *to the students* as a product of their own discovery, which often motivates them for further work. The final diagram needs to be general enough to correspond to as many individual cases as possible: the students will later explore the possibilities and limitations of the diagram in relation to different species, i.e., make a theoretical generalization through the concretization of the diagram.

Based on the table above, we will now discuss the incremental changes in the students' diagrams. The starting point of the work is that students construct their first solution proposals in diagrammatic format, based on the information available to them through the text. Because these initial diagrams are constructed by the students themselves – and not given as suggestions by the teacher – they capture precisely the students' current thinking, not anyone else's thinking. The initial diagrams that students typically construct in this particular biology lesson correspond to diagrams 1-5 and sometimes even diagram 7, see table 1. The diagrams differ in validity regarding:

a) ways of visualization – there are **diagrams with** more or less detailed **sketches** of the mayfly (sketches of egg, imago, adult) and its surroundings, see for example diagram 1; **diagrams**

with words only (“egg”, “mayfly imago”, etc.), see for example diagrams 2-4; **diagrams with symbols** (geometrical figures, letters, etc.); **diagrams with symbols** (geometrical figures, letters, etc.). Differences in visualization reflect different ideas about what the diagram should represent – the life cycle of the mayfly or the life cycle as something that applies to species other than the mayfly alone.

b) the nature of the process – there are diagrams that are **circular**, see for example diagrams 3 and 8; there are diagrams that are **linear**, see for example diagrams 1,2, 4-7. The linear diagrams are closer to the text, and reflect the description of the life cycle of the mayfly as described in the text. In the circular diagrams, the students take a step forward in their thinking and show a transition between adult mayfly and egg.

During the lesson, students successively adjust their diagrams from being very detailed and specific (see diagrams 1 and 2) to more and more general (see diagrams 3 and beyond). In that sense, the students’ diagrams are different versions of *the model-to-be*. The modelling is quite different from the teacher telling the students what something is like. The vast majority of students know from earlier that there are some other species with life cycles. By contrasting a more detailed and mayfly-specific diagram with a less detailed and more general diagram, students’ attention is drawn to the value of expanding the boundaries of the task and constructing a more general diagram that can accommodate more species than just the mayfly. This work reflects the movement from the specific to the general (a theoretical abstraction).

The students come up with the term “mayflyness” when they need a word that captures that there is something common to all the different stages of the mayfly’s life cycle. This word, which is later replaced by the word “information” (then by the word “information carrier”) is a theoretical concept to be – “genetic information”. In working with the diagrams, we can see that the students’ understanding develops before the word is put as a label on a particular meaning. The word “genetic information” is eventually put as a label to grasp what the students have discovered with the teacher’s guidance. It often turns out that even those students who already know the words "genes" and "genetic information" do not connect the meaning of these to the work on the diagrams until right at the end.

Later in the current biology course, when the content is oriented around various animal species, the students use their newly constructed knowledge of genes to assess the applicability of the final diagram to other individual cases – they test the generalizability of the model. When they conclude that other versions are needed that would explain the life cycle of some other species, they adjust the model and thus construct more versions. The key point here is that all modifications or versions of the model will be based on the same general principles. The whole process, from this lesson to later in the biology course, reflects the movement from the specific to the general (theoretical abstraction) and on to the specific (a theoretical generalization). Instruction through which the students develop a theoretical subject-specific concept encompasses the entire modelling process where both theoretical abstraction and theoretical generalization are enabled.

THE FUNCTION OF THE TEACHER'S QUESTIONS AND ACTIONS DURING THE MODELLING. "OWNING" THE GENERAL MODEL AS A PRECONDITION FOR ORGANIZING THE JOINT DISCUSSION

How does the teacher in the teaching example organize and lead the joint activity of modelling so that the general becomes discernible for the students? In the analyzed teaching example, the teacher "owns" the general model – i.e., the 'finished' diagram – from the very beginning. Thus, the general model of the life cycle (see Figure 2) directs the teacher's actions through the modelling as it is the intended goal for the students' work of thought.

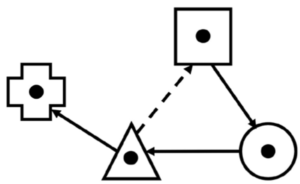

Figure 2: The general model of life cycle.
Source: own elaboration.

By “owning” the general model the teacher is able to prepare in advance how to strategically guide the students’ work of thought. The teacher quickly identifies – among the various initially represented student diagrams – the most non-general and uses it as the starting point of the modelling process. Through the modelling process the teacher repeatedly chooses a version of the diagram, which by contrasting it to the latter, motivates such questions that enable the students to experience a need to make a certain change and adjustment in the current version of the diagram. Solely on the basis of the model as an end product, the teacher is able to ask *such* questions that guide the joint work in the direction of the general model, which makes visible the essence of the object studied. In this way, the teacher constantly draws the students into the joint reflection rather than explains.

To enable the students to work together on their ideas and thoughts about the mayfly’s life cycle and, later, the “mayflyness”, the teacher asks the students to draw their solution proposals so that these are visible on the board. The entire situation of modelling can be seen as “the crossroads of two initiatives (teacher’s and student’s) on the sign” (ZUCKERMAN, 2018, p. 23). At the start of the joint modelling the teacher ensures that all various kinds of current thinking represented in the group of students are available on the board. It is not for sure that the students initially construct for example diagram 7. When the teacher notices that a particular diagram is needed to contrast a current idea – and take the students’ thought one step further towards the general model – the teacher himself/herself can introduce the diagram needed on the board. For example, the teacher sometimes says, “In another class, some students constructed this diagram, what do you think of it?”

The teacher’s questions (see Table 1: “What can you say about this diagram?”, “What is the difference between these two diagrams?”) encourage the students to step-by-step compare different diagrams. The principle of the step-by-step comparison is that a more non-general diagram is contrasted with a more general diagram. In the teaching example, the more non-general diagram 1 or 2 is contrasted with the more general diagram 4. Accordingly, as a starting point for the discussion, the teacher strategically chooses not the best/most correct proposal, but the most non-general one. By doing so, even the students owning the most non-general way of thinking are included, from the start, in terms of having the opportunity to recognize their way of thought on the board. The teacher repeatedly asks all the students to read out loud, in chorus, the diagrams, i.e., to put into words what is written in the diagram. However, it is not the students who drew the diagram who explain it to the other, but the other way round - first, the other students are encouraged to try to read out the diagram and interpret it. In this way, the group of students who constructed the diagram get feedback on whether they were successful in visualizing their current thinking. If the group of students notice that their diagram does not correspond to how they currently think, they are encouraged to adjust the diagram.

The teacher organizes and leads the joint activity of modelling in such a way that theoretical abstraction is made possible for the students. Aspects not possible to experience directly - but which constitute the essential - are brought to the fore, through the discussion followed by adjustments in the diagram. The non-essential aspects, such as mayfly's appearance and the students' descriptions of the environment around it, are brought to the background - by erasing them from the diagram - as a consequence of collective conclusions. This allows the students to discern the essence of the specific example they are working with, and begin the development of a theoretical concept.

CONCLUSIONS

The aim of the study was to explore how the modelling, as a condition for theoretical abstraction and generalization, takes shape in a certain sequence of a biology instruction based on the El'konin-Davydov program. The following research questions were formulated:

– How are the students' diagrams used in the modelling?

– What is the character and function of the teacher's questions and actions in the modelling?

Based on the results of our analysis, the following conclusions can be drawn:

- The students' diagrams visualize the solutions proposed by the students. The different initial solution proposals visualize the variation in current thinking that is represented in the student group. The students' diagrams serve as tools in the joint abstraction process, reflecting the different steps on the way to the common general model, which the work aims to have the students construct as their joint final version.

- The questions and actions of the teacher in the modelling are of the following nature:
    - The teacher ensures that all various kinds of the students' current thinking are available in schematic form on the board before the joint modelling begins.
    - The teacher's questions encourage the students to compare different diagrams step by step. The principle of this successive comparative work is that the most non-general diagram is contrasted with a more general diagram. Therefore, to start the discussion, the teacher strategically chooses not the best/most correct proposal, but the most non-general solution, so that all students have the opportunity to follow and develop the joint thinking.
    - If necessary, the teacher adds the schematic proposal that is missing in this particular group of students, but which is needed in the discussion to allow all students to make a certain adjustment in their thinking.
    - Solely on the basis of the model as an "end product", the teacher is able to ask *such* questions that guide the joint work in the direction of the general model, which makes visible for the students the essence of the object studied. In this way, the teacher constantly makes the students' thinking the object of joint reflection, rather than explaining.
- The teacher organizes and leads the modelling in such a way that theoretical abstraction is made possible for the students. This allows the students to discern the essence of the specific case they are working with and to begin the development of a theoretical concept.

In accordance with research within the cultural historical tradition (ARIEVITCH, 2017; CHAIKLIN, 2019; CHUDINOVA 2019a; DAVYDOV, 1990, 2008; EL'KONIN, 1989; EL'KONIN, 2020; VYGOTSKII, 2001; ZUCKERMAN et al., 1998), formal instruction is not about telling the students what science has come up with, but creating conditions for enabling the students to develop subject-specific theoretical concepts. Hence, we conclude that the meaning given by Davydov (1990; 2008) to the concept of “modelling” is not to be understood in terms of the teacher introducing a ready-made general model, which the students then explore. It should rather be understood in terms of the teacher managing such a joint activity that enables the contentful abstraction and generalization, so that the students develop the theoretical concept in question.

Notes

1 Here, theoretical knowledge is to be understood as “contentful abstraction and generalization and theoretical concepts, taken as a unity” (DAVYDOV, 2008, p. 116).

2 These schools in Moscow are experimental schools within the Elkonin-Davydov program.

3 Notice that the concept of organism is not used here. *Organism* is another concept, which the students are about to develop later in the biology course

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