Modeling Tasks for Exploring Topics of High-School Biology in the Computer-Supported Educational Environment '*ModelsCreator*'

Vassiliki Zogza, Marida Ergazaki, Vassilis Komis
Department of Educational Sciences and Early Childhood Education
University of Patras, Greece
zogza@upatras.gr, ergazaki@upatras.gr, komis@upatras.gr

Abstract. *This paper reports on part of our work for the project 'ModelsCreator' in regard with the didactic approach of specific topics within the secondary biological education. Considering the already reported difficulties of high-school students in adequately grasping complicated biological processes of abstract nature such as photosynthesis or inheritance, we developed corresponding educational scenarios within the computer-supported environment 'Models Creator' to be implemented in experimental as well as in real classroom settings. The development of these scenarios which include a series of modeling tasks organized in students' worksheets is discussed here.*

Keywords. Computer-Supported Modeling, High-school Biology, '*ModelsCreator*', Plant growth, Photosynthesis, Inheritance.

1. Introduction

A number of computer-supported educational environments have recently been developed in a '*socio-constructivist*' theoretical framework ([4], [18]) with the aim of supporting the teaching and learning process in a qualitatively different way ([5], [10]). Such environments attempt to give students the opportunity to express, explore and refine their mental representations about natural phenomena by providing them with appropriately designed building and testing tools ([17]). Thus, computer-supported dynamic modeling is employed in order to facilitate students' active engagement in a process of integrating specific parts of knowledge into broader explanatory or merely descriptive mental structures ([15], [16]).

'*ModelsCreator*' is a computer-supported educational environment that - apart from purely qualitative or purely quantitative approaches to the natural world, such as concept maps or mathematical models- allows for semi-quantitative modeling as well as for modeling with logical operands (i.e. IF, AND, OR, THEN) (http://www.ecedu.upatras.gr/modelscreator/). It practically constitutes an 'open' modeling environment where students are supposed to analyze problems in terms of *'objects'* relevant to the problem, *'properties'*, that is factors characteristic of these objects and finally *'relationships'* between the *'properties'* of one or more *'objects'*.

The type of *'relationships'* actually defines the type of modeling. In case of using semi-quantitative reasoning, namely mathematically informed *'relationships'* of qualitative character, students are able to construct semi-quantitative models, while when using logical operands they can come up with models of logic.

In this paper, we present two educational scenarios we developed for the environment of *'ModelsCreator'*. The first one, 'Photosynthesis & Plant Growth', focuses on photosynthesis not only as a biochemical process, but also as an essential parameter of plant growth and engages students in the construction of semi-quantitative models. On the contrary, the second one, 'Inheritance', requires the construction of models of logic having to do with the way that dominant or recessive genes located on autosomic or sex chromosomes pass from parents to offspring.

The questions to be highlighted for both scenarios hereafter are:

- Which is the theoretical background for developing each educational scenario and which are the aims of it?
- Which are the suggested modeling tasks within the environment of *'ModelsCreator'* and which are the underlying didactic objectives?

2. The educational scenario of 'Photosynthesis & plant growth'

Research on students' expressed models about photosynthesis and plant nutrition has actually revealed a series of cognitive obstacles ([6]). Some of them in regard with the concept of *'food'* and its environmental origin seem to derive from transferring the animal model of *'heterotrophic nutrition'* to plants. Several studies have actually shown ([19], [20]) that students of different ages find it rather difficult to realize that plants produce their own food instead of taking it in from the environment. Having serious difficulties in understanding *'food'* as a source of energy and building blocks necessary for an organism's growth and maintenance to life, students frequently identify *'soil minerals', 'oxygen', 'carbon dioxide'* or *'water'* as *'food molecules'* on the basis of being externally provided to plants and generally contributing to their well being ([3]).

The concepts of *'energy'* and *'energetic transformations'* within living organisms and especially plants seem also to raise serious obstacles ([14]). Students have trouble in understanding sunlight in terms of *'light energy'* which needs to be transformed into *'chemical energy'* by plants in order to become available to all living things through food webs.

Finally, the concepts of *'air'* and *'soil'* as well as the one of *'chemical reaction'* are problematic, too ([13]). This is rather expected since students are required to realize that an unobservable gas (carbon dioxide) *and* a liquid (water) within the 'solid' and 'compact' soil are taking part in a biochemical mechanism (photosynthesis) in the interior of the plant to finally become its *'food'*.

In the light of these data from the domain of Biology education research, a didactical approach of photosynthesis on the biochemical level of a *'reaction'* transforming unobservable chemical substances does not seem to be meaningful enough to young students. On the contrary, setting photosynthesis in the context of the observed phenomenon of plant growth and studying it in terms of a *'food making'* process could probably support students in constructing knowledge-based links between the macro level of the environmentally affected plant growth which is easier to conceptualize and the micro level where the photosynthetic mechanism lays ([7]). In other words, it might help students to use the latter as an explanatory framework for the former, instead of considering it as an isolated piece of hard to remember school science.

This idea upon which we've actually developed our educational scenario within *'ModelsCreator'* can also be traced in the biology schoolbooks used the last few years in secondary education in Greece. In the 1st grade *'Biology'* ([8]), photosynthesis is briefly presented in the context of the exclusive characteristics of living organisms and specifically in the sub-context of growth, while it is further examined in the context of nutrition. In both cases there is a common pattern of connecting the growth of every living organism with energy, the energy with the breakdown of food and finally -especially for plants- the food with photosynthesis. Students are provided with a simplified form of the photosynthetic reaction and are introduced to the idea that plants use 'material' from their environment to make into their own body glucose, their food. The ecological dimension of photosynthesis is also pointed out through the categorization of the organisms of an ecosystem as *producers, consumers or decomposers* and the introduction of the concepts of *food chain and food web.* This aspect is actually the main focus in the 3rd grade *'Biology'* ([1]).

However, establishing a meaningful inter-connection of photosynthesis and plant growth through food and energy -which is actually the aim of this educational scenario- is not an easy task. Attempting to reduce the cognitive load associated with the *abstract* nature of the topic by providing students with visual representations of the employed concepts instead of requiring from them to be restricted to their own imagination, seems quite purposeful. Thus, in the environment of *'ModelsCreator'* students can have a dynamic view of the used objects (i.e. plant, leaf, air), first according to the specific concepts they activate for each of them (i.e. food, photosynthesis, carbon dioxide). Of course, it is not argued that such symbolic representations (i.e. cyclic arrows of different size for different 'rates' of photosynthesis) could in any case completely reduce the status of theoretical concepts like *'light energy', 'chemical' energy'* or *'biochemical reaction'* from 'abstract' to 'concrete'. However, it is our view that it might help students in organizing their ideas into a visual dynamic 'web', appropriate for reflection with the teacher and introduction of the target scientific ideas. For instance, representing both 'plant's food' and 'leaf's glucose' with same-colored hexagons within *'ModelsCreator'*, may provide an initial visual framework for students' effective introduction to the idea that the six-carbon sugar of glucose produced in a plant's leaves *is* actually its food.

More specifically, the environment of *'ModelsCreator'* for this educational scenario consists of a set of 5 *objects*, each having a subset of *properties*: PLANT (growth / food / energy), SOIL (water / minerals), SUN (light), AIR (oxygen / carbon dioxide), LEAF (carbon dioxide / water / photosynthesis / glucose / oxygen). Furthermore, there is a set of *semi-quantitative relationships* (i.e. 'increases-increases', 'increases-decreases' or 'increases-increases less') upon which students draw to define the *inter-connections* of the given structural elements they wish in a more formalistic manner.

The construction of a model requires selecting '*objects'*, moving them in the working space, selecting '*properties'* for each *object*- the visual representation of which is accordingly changed- and also connecting the '*properties'* with '*relationships'* selected from the given set. After having completed their model, as well as at any point in the process of constructing it, students have the option of testing its behaviour by making use of the built-in testing tools of the software.

But how exactly do we pursue the aim of supporting high-school students in establishing a meaningful link between photosynthesis and plant growth in the *'ModelsCreator'* environment just described?

The educational scenario is consisted of five one-hour tasks, organized in worksheets which are divided in 2 parts. In the 'Task-part', students are assigned with a specific modeling task and being provided with basic technical instructions regarding the modeling process within the environment of *'ModelsCreator'*. On the other hand, the 'Let's think'-part requires from students to explore instructional questions in the light of which they could possibly think about their model more scientifically.

The five-task sequence is initiated with shaping the organizing framework of plant growth on the basis of the concepts 'food' and 'energy'. Dealing with the first modeling task, students focus on 'food' as an essential requirement for the 'growth' of all living organisms - and consequently for plant growth - and they are actually required to expand the relationship of 'food' and 'growth' through the concept of 'energy'. Thus, they are supposed to come up with a serial model where all the three *'properties'* of the *'object'* 'plant' - 'food', 'energy', 'growth' - are inter-connected so that each functions as a prerequisite for the next one.

Introducing the idea that *'food is required for plant growth since it is the source of the required energy',* this task actually leads to the key issue of *'where do plants get their food?'*. Focusing especially on whether or not *'plants get their food from the soil',* the next task -'Plants and Soil'- aims at destabilizing the most commonly held misconception at all ages. In the light of a leading experiment set up by Van Helmont in the 17^{th} century, students are required to explore a ready-made model where soil minerals are wrongly presented as plant's food. This authentic experiment offers the opportunity of a potentially powerful cognitive conflict between the provided model which reflects the target misconception and the 'facts' as revealed through Van Helmont's appropriately designed measurements. Students are supported in interpreting the experimental results they are provided with for developing a reasoning strand like:

- 'If the soil was *indeed* the source of plant's food and thus responsible for its growth, then the increase of plant's 'weight' measured by Van Helmont *should be* similar to the decrease of the soil's weight', but
- 'Since the former is found to be excessively more than the latter according Van Helmont's results, then the source of plant's food must be searched elsewhere than the soil itself'.

So, after attempting to seriously challenge the highly resisting idea of the soil being plants' food source, we set our focus on the 'photosynthesis'-mediated inter-connection of two environmental factors with plant growth, making also use of the 'energy'-mediated inter-connection of 'food' & 'growth' already explored in the first task.

Thus, the next two tasks -'Plants and Sun' and 'Plants and water'- aim at supporting students in explaining the effect of the environmental factors sunlight and soil water on plant growth by appealing to their relationship with photosynthesis considered as a food-making process. In other words, students are required to come up with models connecting each environmental factor with plant growth through photosynthesis, which is to be further inter-connected with glucose, food and energy.

Finally, the last modeling task of this educational scenario examines photosynthesis as biochemical reaction. Students are required to construct a model upon the *'object'* of leaf by activating all its five *'properties'* and interconnecting them with each other to show that the light-driven photosynthetic mechanism located into plant's leaves requires water and carbon dioxide in order to produce glucose and oxygen. This task may also function as a basis for enhancing students' interest in photosynthesis invoking oxygen production. Pointing out that photosynthesis makes possible for plants to produce oxygen which is subsequently released in atmosphere and becomes available to all living organisms that depend on it for their own survival, can possibly result in recognition of photosynthesis' key role in the living world.

3. The educational scenario of 'Inheritance'

Genetics is considered to be one of the most demanding biological topics ([2], [11]). Research in the domain of Biology education has revealed a number of cognitive obstacles deriving from the *'complex and abstract'* nature of the topic ([9]). In fact, students are presented with an extended series of rather complex and abstract concepts, which are required to understand and furthermore interconnect, in order to come up with the view of inheritance that the school science dictates.

A rather long list of difficulties encountered by students when dealing with high-school genetics and of the alternative conceptions that they seem to hold - sometimes even after they have been taught in class-, is actually available. Such misunderstandings may concern inheritance of acquired characteristics (i.e. characteristics acquired through parents' lifetime are thought of as transmittable to offspring), parental contribution to the genetic profile of offspring according to their sex (i.e. daughters are thought of as most likely inheriting maternal characteristics, while sons paternal ones), genes as the '*material entities'* passing from parents to offspring and finally the idea of probability as the key parameter in the process of inheritance ([12]).

Moreover, the mechanism that underlies the formation of sex cells and consequently the inheritance itself - the so-called meiosis - is usually studied separately from the transmission of specific genetic traits from parents to offspring ([9]). However, such a didactic option can not actually support students in developing a deep understanding of the topic. On the contrary, it is possible to encourage them in coming up with standard solutions to the required genetic crosses without really being aware either of simulating meiosis when separating 'letters' - that is *alleles* - to define gametes - that is *eggs and sperms -,* or of how important randomness is in this process.

The educational scenario that we developed for the computer-supported educational environment *'ModelsCreator'* aims at supporting students in getting more familiar with the probabilistic character of inheritance on the basis of recognizing meiosis as the underlying process.

Since genetics may be discouraging to a significant part of young students due to its increased cognitive load, we attempted to enhance the motivation for studying it carefully by assigning students the role of an imaginary genetic counselor responsible for making reliable predictions about the possible offspring of couples having specific genetic profiles. Thus, students are presented with a series of family situations that mainly concern the appearance of specific human diseases and then they are asked to inform each couple of future parents about the possibility of having offspring suffering from the disease that is in question each time.

The environment of *'ModelsCreator'* for this educational scenario provides a set of five *objects*: WOMAN, MAN, CHILD, BOY, GIRL. Each of them has a sub-set of five *properties*: Thalassaemia, Huntington Disease, Hair Type, Color Blindness and Haemophilia. Each *property* has either three ('sick', 'carrier', 'healthy') or two *values* ('sick', 'healthy') and each *value* may be tagged with a *probability* ranging between 0 and 1. Students are also provided with a set of logical operands (IF, THEN, AND, OR, NOT) upon which they draw to set up the required genetic crosses in terms of qualitative reasoning (i.e. IF the woman is sick with x AND the man is x's carrier, THEN each child of the couple has an a% probability of being sick with x, a b% probability of being x's carrier and a c% probability of being healthy regarding x').

The construction of a model requires selecting '*objects'*, moving them in the working space, selecting *one* same '*property'* for each *object* (since the software does not allow for the study of dihybrid genetic crosses), selecting *values* for each *object's property*, defining a *probability* for each value (which results in a change of the object's visual representation) and finally selecting logical operands from the given set to set up the target genetic cross. After having completed their prediction about the couple's offspring through constructing a model of logic, students have the option of testing the validity of their prediction by comparing their own model with the one saved earlier in the software by their teacher as a *'model of reference'*.

So, how exactly do we pursue the aim of supporting high-school students in coping with the probabilistic character of inheritance within the described environment of *'ModelsCreator'*?

The educational scenario is consisted of five one-hour tasks, similarly organized in students' worksheets. In the beginning of each worksheet, students are assigned with the 'mission' of predicting the offspring of a couple usually on the basis of specific information about a genetic trait of the couple itself or of their parents.

Before being provided with basic technical instructions about the modeling process within the environment of *'ModelsCreator',* students are faced with a number of questions which they are supposed to explore as a prerequisite for the construction of their model within the software. These questions practically aim at supporting students in organizing their thought around the idea of *'probability'* in order to come up with valid predictions.

After modeling their predictions, students are required to test their model against a *'model of reference'* and moreover to focus on meiosis, the mechanism that underlies the formation of eggs and sperms. Thus, in the last part of each worksheet students are first asked to draw one body cell of the mother and one body cell of the father, as well as the nucleus of each, where they are supposed to add only one pair of chromosomes with the alleles for one specific trait as dictated by the task. Then, they are given the necessary instructions in order to have a 'paper & pencil' simulation of meiosis resulting in possibly different sex cells, which they finally have to combine in all possible ways to come up with all possible cases for each child of the couple. In the light of the above, students have the option of revising their model in order to reflect a possibly different understanding of the genetic cross they are working with.

The five tasks of the scenario deal with genetic traits -mainly human diseases- that have been selected on the basis of the type of the responsible gene. Thus, the first two tasks concern the inheritance of autosomic genes, recessive in the case of Thalassaemia, while dominant in the case of Huntington Disease. On the contrary, the last two tasks concern the inheritance of recessive sex-linked genes in both the cases of Colour-Blindness and Haemophilia. Finally, the inheritance of a special type of genes, the so-called co-dominant genes, is the only one not studied in the context of a disease but of the hair-type trait.

Analyzing the scenario tasks a little bit further, we should notice that the first one, set in the context of Thalassaemia, is rather 'open'. Aiming at presenting students with the idea that multiple genotypic and phenotypic combinations may be possible on the individual as well as on the couple level, this task does not provide students with concrete information about the couple's phenotypic or the genotypic profile for Thalassaemia to have them engaged in combinatorial thinking. Thus, students have to come up with all the possible combinations within the couple, which practically means to set up six different genetic crosses. This actually requires that students also realize that reverse crosses like for instance 'woman / sick x man / healthy' and 'woman / healthy x man / sick' may be omitted since they would result in identical offspring because of the gene-type responsible for Thalassaemia.

Exploring then how the Huntington Disease, caused by a dominant autosomic gene, is passed from generation to generation, students are not provided directly with information about both the candidate parents. Knowing only about the woman's father, students first need to set up a cross for the family she comes from and define her possible genotypes for the disease. Based on this first model, they have then to proceed in setting up a new cross concerning the family that the woman plans to have and come up with the possibility that she gives birth to a sick child every time she gets pregnant.

On the contrary, in the third task students are provided with both the future parents' phenotypes regarding the hair-type trait, as well as with the necessary information about the phenotypic expression of co-dominant genes. Thus, after defining the couple's genotypes in the light of the above, students have to set up only one genetic cross to make their prediction about each child of the couple.

Having explored the transmission of three types of autosomic genes, students are next introduced to the inheritance of sex-linked genes. In the fourth task, they are required to predict the possibility of a colour-blind child being born from a sick woman and a healthy man in each pregnancy. Because of the gene-type, students now need to realize that the *'object'* child wouldn't be good enough for their model. On the contrary, they have to set up a genetic cross resulting in girl and a second one resulting in a boy. Furthermore, students are prompted to set up the reverse cross and realize that in case of sex-linked genes reverse crosses may result in quite different offspring.

Finally, in the last task students are required to predict the possibility of a haemophiliac child being born from a carrier woman and a sick man in each pregnancy. Thus, they have the chance to go once more through the ideas that the sex of the child is important when studying the inheritance of sex-linked genes, as well as the sex of the parent who is sick or carrier. Finally, attempting to set up the reverse cross this time, students are practically faced with the idea that the concept of 'carrier' in the case of sex-linked genes is not applicable in males.

4. Acknowledgements

This study was made possible due to financial support by the Project 'Pythagoras' of the Greek Ministry of Education, the ModelsCreator / Pinelopi Project of the Greek Ministry of Education and the IST2000/ModelingSpace Project of the European Union.

5. References

[1] Andriotis M., Georgouli-Markaki L., Guvra M., Katsorxis T., Pavlidis G. Biology - 3rd Grade of High-School. Athens: OEDB; 1999

[2] Bahar M., Johnstone A.H., Hansell M.H. Revisiting learning difficulties in Biology. Educational Researcher 1999; 33(2):84-86.

[3] Bell B. Students' ideas about plant nutrition: What are they? Journal of Biological Education 1985; 19 (3): 213-218.

[4] Brown J., Collins A., Duguid P. Situated cognition and the culture of learning. Educational Researcher 1989; 18 (1): 32-42.

[5] Dimitracopoulou A., Komis V., Apostolopoulos P., Politis P. Design principles of a new modelling environment for young students, supporting various types of reasoning and interdisciplinary approaches. In: Lajoie S., Vivet M. editors. Proceedings of the 9th International Conference on Artificial Intelligence in Education; 1999 July 19-23; Le Mans, France. Le Mans: Université du Maine; 1999. p. 109-120.

[6] Eisen Y., Stavy R. Students' understanding of photosynthesis. American Biology Teacher 1988; 50(4): 208-212.

[7] Ergazaki M., Komis V., Zogza V. High-school Students' Reasoning while Constructing Plant Growth Models in a Computer-Supported Educational Environment. International Journal of Science Education, in press.

[8] Kastorinis A., Katsorxis T., Mourouzi-Manousou E., Pavlidis G., Peraki V., Sapnadeli-Koloka A. Biology - 1st Grade of High-School. Athens: OEDB; 1999

[9] Knippels M.C., Waarloo A.J., Boersma K.T. Coping with the abstract and complex nature of genetics in upper-secondary biology education – Interim Report on a developmental research project. In: Gayoso I., Diaz de Bustamente J., Harms U., Jimenez M.P. editors. Proceedings of the III Conference of European Researchers in Didaktik of Biology; 2000 Sep-Oct 27-1; Santiago de Compostella, Spain. Santiago de Compostella: Universidade de Santiago de Compostella; 2001. p. 87-99.

[10] Komis V., Dimitracopoulou A., Politis P., Avouris N. Expérimentations sur l'utilisation d'un logiciel de modélisation par petits groupes d'élèves. Sciences et techniques éducatives, Hermes 2001 ; 8 (1-2) : 75-86.

[11] Lewis J., Wood-Robinson C. Genes, chromosomes, cell division and inheritance – do students see any relationship?. International Journal of Science Education 2000; 22(2):177-195.

[12] Lewis J., Wood-Robinson C. Genes, chromosomes, cell division and inheritance – do students see any relationship?. International Journal of Science Education 2000; 22(2):177-195.

[13] Smith E.L, Anderson C.W. Alternative student conceptions of matter cycling in ecosystems. Paper presented at the Annual NARST Meeting, 1986. San Francisco: California.

[14] Solomon J. How children learn about energy. School Science Review 1982; 63 (224):415-422.

[15] Soloway E., Guzdial M., Hay, K.E. Learner-centered design: the challenge for HCI in the 21st century. Interactions 1994; 1 (2): 36-48.

[16] Stratford S. J., Krajcik J., Soloway E. Secondary students' dynamic modeling processes: analyzing, reasoning about,

synthesizing, and testing models of stream ecosystems. Journal of Science Education and Technology 1998; 7 (3):215-234.
[17] Vosniadou S., De Corte E., Glaser R., Mandl H. International Perspectives on the Design of Technology-Supported Learning Environments. New Jersey: Lawrence Erlbaum Associates Publishers; 1996.
[18] Vygotsky L.S. Mind in Society: The development of higher psychological processes. In: Cole M., John-Steiner V., Scribner, S., Souberman E. editors and translators. Cambridge: Harvard University Press; 1978.
[19] Wood-Robinson C. Young people's ideas about plants. Studies in Science Education 1991; 19:119-135.
[20] Zogza V., Oeconomopoulou P. Conceptions of students' aged 10-14 about plant nutrition and photosynthesis. Pedagogical Review (Greek Journal) 1999; 107: 75-96.