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IMPROVING STUDENT CONCEPTUALISATIONS THROUGH MANIPULATION IN A WEB-BASED LEARNING ENVIRONMENT

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***Abstract**: This study investigates ways in which students can improve their conceptual understanding of complex biological processes. A model of protein synthesis from the Web-based learning environment Cell World was studied by 59 French students. Students had to manipulate certain virtual molecules so that they would react as a biological phenomenon. Questions on a worksheet investigated student understanding of the ontological categories of objects and processes under the influence of the manipulable and non-manipulable model components. The results of the study suggest a trend wherein the category of processes was less understood than those of objects. However, the outcome also demonstrates that manipulation of a virtual environment can help students to understand the category of processes, rather than merely the properties of objects. Thus, Cell World should be considered as an efficient process-based environment.*

Keywords: *Ontological categories, web-based learning, models, manipulatives, conceptualisation*

I. INTRODUCTION

a. Conceptualisation through ontological categories

Smith [1] defines ontology as "*the science of what is, of the kinds and structures of objects, properties, events, processes and relations in every area of reality*". The concept of ontology, derived from this philosophy, is also used in the domain of education. Thus, Chi [2] has explained that the conceptual structures of learners can be categorised into two main groups of ontological status: the category of objects and the category of processes as interactions between objects. In order to avoid misconceptions, it is necessary to develop a correct mental model of scientific phenomena where an understanding of both ontological categories is necessary. The main problem, as listed by researchers, is the lack of ontological status of processes in the correct conceptual structures of learners. Indeed, Chi [2] has demonstrated the difficulties students have in conceptualising physics concepts such as light, heat, or electric current correctly. Moreover, several concepts in other scientific fields were analysed in the light of learners' ontological understanding, e.g. Ferrari and Chi [3] with the concept of natural selection, and Vosniadou [4] with the ontological status of planets and stars. These studies demonstrated the trend in certain students to limit their conceptualisation of scientific phenomena through the category of objects, and a lack of processes to build valid scientific mental models. The same observation was made by Pata & Sarapuu [5] in the context of educational technologies. For them, a correct mental model in a problem situation should result from an understanding of object properties and the events involving these objects. In this way, dynamic virtual environments should help learners to create correct conceptualisations of scientific phenomena, especially when students use process-based models during learning activities.

b. Virtual manipulatives and non-manipulatives

Moyer et al. [6] explained the possibility of distinguishing two main categories of virtual representation.

1) Static visual representations – they are mostly static and non-manipulable pictures (not able to move, be rotated, *etc*.).

2) Dynamic visual representations, – they may be non-manipulable or manipulable by a user of the learning environment: non-manipulatives and manipulatives.

More precisely, a virtual manipulative is defined as "an interactive, Web-based visual representation of a dynamic object that presents opportunities for constructing mathematical knowledge" [7]. When this definition was firstly applied in the field of mathematics, every dynamic and manipulable object for constructing scientific knowledge could also be considered. In the current study, French students have used a model explaining biological mechanisms of protein synthesis (http://bio.edu.ee/models/en/). All molecules of this model are dynamic (they participate in animations) while some are manipulable and some are non-manipulable. The active-learning hypothesis, originating in constructivism, predicts that manipulations improve depth of learning [8]. Thus, with interactive activities, learners are the main actors in the construction of their own scientific concepts. According to this hypothesis, a deeper conceptualisation will be possible when manipulatives are involved. Cognitive Load Theory [9] can also help to interpret the role of manipulations in a virtual environment. A germane cognitive load is the consequence of activities that enhance acquisition of knowledge structures by optimising learner attention to cognitive activities that are directly relevant to concept construction [10]. Chandler [11] also explains a possibly contradictory consequence of using manipulatives by explaining that interactive exercises involving animations may induce heavy extraneous cognitive load. If interactive materials are not designed to reduce this cognitive load, learners may be engaged in extensive activities unrelated to learning. Consequently, an overload of short-term memory could engender major problems in learning activities. This possible problem was considered in this study.

c. Aim of the work and research questions

The aim of this study is to investigate ways in which students can improve their conceptualisation of complex biological processes. The impact of model component properties is investigated from a conceptualisation perspective. Specifically, this work tries to answer the following questions:

- What do learners understand about ontological categories of objects and processes?
- How do the manipulatives and non-manipulatives help learners conceptualise through ontological categories?

II. METHODS

2.1. Learning environment

The Web-based learning environment Cell World (http://bio.edu.ee/models), used in this study, consists of 10 interactive models where students can participate in the different biological processes of a cell. These models were designed by the Educational Technology Workgroup at the Science Education Centre of the University of Tartu, with a specific objective of shifting student understanding from the ontological category of objects to the category of processes. Cell World leads to focused attention from students on the interactions between model components as well as the properties of the components.

In the present study a model of protein synthesis (*translation*) was studied. The components of this model can be divided into two groups: molecules which are manipulable and those which are non-manipulable. Both are involved in dynamic animations which represent protein synthesis (Figure 1). For the three tasks for the model, it is necessary to add the correct molecules to the animation in order to continue the protein synthesis. Simultaneously, students completed a worksheet depending on the model used.

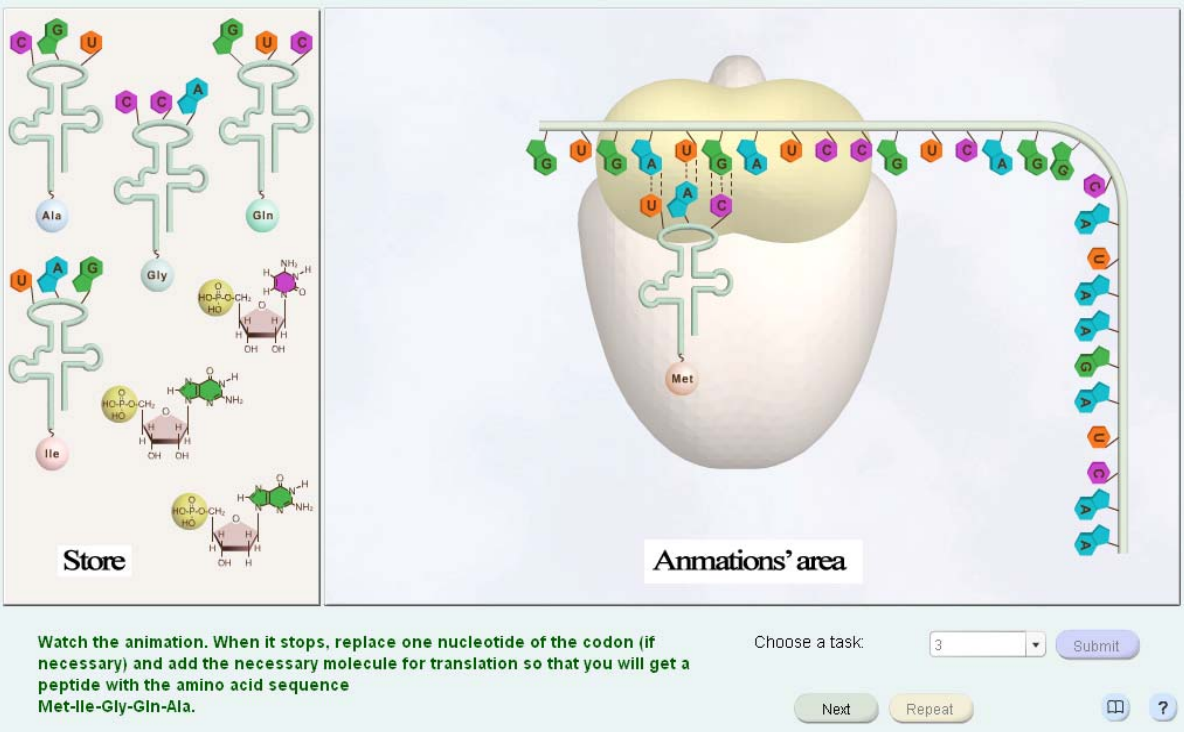

Figure 1. Manipulatives (molecules in the store) and non-manipulatives (molecules in the animations' area) of the Web-based environment Cell World.

This model was designed in order to develop learner understanding of the different interactions of molecules during protein synthesis. Students can move each manipulative from the store (on the left of the screen) to the area of non-manipulative animations (on the right of the screen, see Figure 1). If the manipulative selected is incorrect, learners receive feedback which instructs them to drag the correct manipulative instead, in order to continue the animation. When the manipulative is correct, students can observe interaction between manipulatives and non-manipulatives.

2.2. Worksheet

A worksheet with instructions was developed to help students to use the environment correctly. The worksheet also included ten questions to investigate student understanding of ontological categories of objects (four questions) and processes (six questions). Students must complete the worksheet and complete three different tasks on the modelling screen in forty-five minutes.

Table 1: Examples of worksheet questions

Questions on processes		**Questions on objects**	
Manipulatives	**Non-manipulatives**	**Manipulatives**	**Non-manipulatives**
Why can't the tRNA, which transports Gly amino acid, be linked to the mRNA?	What are the main activities of mRNA?	What is the difference between the two nucleotides G in the store?	Why does the translation end?

Questions on the worksheet can be divided into two main groups and four sub-groups – see the examples in Table 1. Every question tests student understanding of the ontological categories of processes or objects. The questions about processes lead students to think in terms of emergent interactions between objects, and the questions about objects require them to use specific knowledge about the properties of a molecule. These two main categories can also be divided into questions about model components: either manipulable molecules or non-manipulable molecules. In short, these questions evaluated the way students understand ontological categories according to the use of manipulatives or non-manipulatives. To evaluate student ontological understanding, a maximum of 12 points for each category (processes and objects) was given. Each question was assessed with a maximum of two points if it was correct, one point for partly correct answer and no points for a wrong or missing answer. A maximum of 6 points was given for one question about the object category.

2.3. Participants

Fifty-nine French high school students of the sciences (16-17 years old) used the model. This level corresponds with the class to which protein synthesis is taught. The sample comes from three different French schools of average intake.

Before grouping the schools some statistical precautions were taken. According to the worksheet results, the difference between the three schools was not significant. A Kruskal-Wallis test was done on the student assessments derived from the worksheets ($H= 0.308$, $df=2$, $p= 0.857$). Due to a lack of working computers in the school computer laboratories, some of the students worked in pairs ($2n=14$) and others individually ($n=31$). A Mann-Whitney U Test was used to compare students who worked in pairs and those who worked individually. No significant difference was found between these two groups ($Z=-0.466$, $p=0.642$). Consequently, further comparisons were made regarding the group as one sample of learners.

III. RESULTS AND DISCUSSION

3.1. Ontological categories and student understanding

In order to characterise the students' understanding of the ontological categories of processes and objects, mean scores of their worksheet answers were calculated (Table 2).

Table 2: Students' mean scores in the ontological categories

Ontological categories (maximum score = 12)	Mean	% of the total score	SD
Processes	7.46	62	2.18
Objects	7.86	65.5	2.61

The means of both categories were very similar – 7.46 for the processes and 7.86 for the objects (out of 12 points). This descriptive analysis shows only a small trend suggesting that the students understand the category of objects better than processes. This tendency is low and only a bigger sample of students could confirm the trend.

Nevertheless, researchers have shown in physics [2], astronomy [4], and biology [3], that a student's deep understanding of scientific concepts depends on their ability to conceptualise through processes. They have also demonstrated major difficulties amongst learners in understanding the ontological category of processes better than the objects in problem solving cases. In our study, this tiny difference, between students' mean scores for understanding processes and objects is probably due to the use of the virtual environment. Indeed, the models have been designed precisely to improve student understanding of biological processes. Pata and Sarapuu [5] have described a problem concerning the traditional way of teaching biology by focusing on the ontological category of objects. Thus, Cell World contributes to helping students to focus their mental activities on the interactions of molecules during biological processes.

3.2. Influence of manipulatives on ontological understanding

Next, we investigated the influence of the two groups of model components – manipulatives and non-manipulatives – on student ontological understanding. The worksheet questions were subdivided into groups of manipulatives and non-manipulatives for each ontological category. Table 3 shows the students' mean scores according to the groups of model components and the ontological categories.

Table 3. Student mean scores according to model components and ontological categories

Model components — ontological categories (maximum score)	Mean score	% of total score	SD
Manipulatives — processes (6)	4.85	80	1.42
Non-manipulatives — processes (6)	2.61	43.5	1.52
Manipulatives — objects (4)	3.22	80.5	1.49
Non-manipulatives — objects (8)	4.64	58	1.65

We can see a very clear tendency for the use of manipulatives to increase understanding of the category of processes. When manipulatives are involved, 80% of the total score is obtained but only 43.5% in case of non-manipulatives. When manipulatives are involved in the objects category 80.5% of the total score is completed whereas for non-manipulatives it is 58%. Thus, the use of manipulatives seems more efficient for increasing understanding in the category of processes rather than objects.

Table 4 expresses the number of students who performed better in each ontological category according to whether they were manipulatives or non-manipulatives.

Table 4. The number of learners demonstrating more understanding about manipulatives or non-manipulatives in the ontological categories

Model components / Ontological categories	Manipulatives	Non-manipulatives	Equal	Total
Processes	49	6	4	59
Objects	42	9	8	59

According to Table 4, 49 learners understood the category of processes better with manipulatives, six students better with non-manipulatives and four learners obtained the same results for manipulatives and non-manipulatives.

The results are comparable for the ontological category of objects. Forty-two students understood manipulable objects better, nine students non-manipulatives and eight learners equally non-manipulatives and manipulatives.

Thus, Table 4 furnishes clear evidence that when students can manipulate objects, the properties and possible interaction of these objects are better understood. As shown in the first part of the study, learners usually have more knowledge in the category of objects. However, when manipulatives are involved, the understanding in both ontological categories is enhanced.

When considering Cognitive Load Theory, the germane load seems to be positively enhanced by manipulations. Therefore, non-manipulatives are less understood in terms of the ontological category of processes as well as objects. Our results are in accordance with the investigations of Bodemer et al. [10]: the consequence of the germane cognitive load induced by utilising interactive representations can be better conceptualisation by students. They explain that the use of interactive animations induces "active learner behaviour and constructive learning processes". Hence, the germane cognitive load, which is a result of mental activities, seems to be better activated when it is induced by the interactive exercises in Cell World. Moreover, heavy extraneous cognitive loads, due to the large amounts of continuously changing information noticed by Chandler [11], do not impact the learning process in the present study when dynamic interactive representations are involved.

IV. CONCLUSIONS

The aim of this study was to investigate how students can improve their conceptualisation of complex biological processes. Students applied a process-based model with the help of a worksheet. The student answers of 10 worksheet questions about the ontological categories of processes and objects were analysed.

The first part of this study demonstrates that students express a small trend of greater difficulty in understanding the category of processes over objects. The finding supports previous research that has demonstrated greater difficulties in learner understanding of processes. This difference could be attributed to the process-based environment used in the present study. The main challenge for teaching scientific phenomena is to lead learners to shift their understanding from the ontological category of objects to the category of processes. Thus, these outcomes suggest that Cell World is a relevant learning environment.

The second part of our research shows how the use of manipulatives, compared to non-manipulatives, can help learners to increase their understanding of the ontological category of processes, whether or not their understanding of objects is also improved. Thus, introducing manipulatives, at the most critical point of a scientific model, supports learners to better conceptualise scientific phenomena by improving understanding, especially in the category of processes.

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