Information-processing and conceptual change in network-based synchronous modeling environments

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Abstract: The study investigated the development of 53 students’ representations about a genetic problem while performing exploratory and expressive modeling in a synchronous environment. The influence of collaborative scientific representation on individual conceptual development was studied by analyzing students’ verbal representations at different phases of the activity. During expressive modeling the initial situation models were revised by adding new elements from the conceptual materials and the conceptually enriched situation models were represented after the activity. Exploratory modeling demanded the activation of two different mental models and the validation of the elements from the situation model by holding the representation of the conceptual model active in short-term memory. In our experiment this process was performed mainly at one direction and the formation of conceptually enriched situation models appeared to be inhibited.

Keywords: conceptual development, expressive & exploratory modeling, synchronous learning.

1. Introduction

The learning environments can be categorized in terms of their representational capabilities as exploratory (simulations) or expressive (whiteboards, argument-graphs, mind maps, etc.) (Chalk, 2000). The current research aimed to study the effects of two types of collaborative scientific representation on individual conceptual development. The influence of working with exploratory and expressive tools in synchronous network-based environment was studied from the perspective of changes in the structure of students’ verbal representations. We discuss the theoretical sequence of conceptual development from the cognitive information processing aspect, proposing that the nature of modeling has to be considered while designing the learning activities.

Numerous studies characterize conceptual development through the transformations in learners’ way of representing phenomena. From each phenomenon various internal and external representations can be formed. The former are mental models, the internal simulations performed in short-term memory (Gentner & Gentner, 1983; Johnson-Laird, 1989), while the latter cover a wide variety of verbal or visual artefacts represented orally, in written format or by means of different design elements, etc. that are created deliberately as a part of cognitive process, rather than for pragmatic ends (Zhang & Norman, 1994). If the scientific explanations are not taught to people, they represent phenomena with simplified mental models that describe the surface features of objects and processes. The researchers, teachers, engineers and other specialists in certain domains are able to compose conceptual mental models that reflect their in-depth understanding of the systems. They can also develop conceptual external representations of the phenomena – conceptual models – that enhance teaching or which can be used in the comprehension process (Greca & Moreira, 2000). In this framework teaching for conceptual change comprises dealing with students’ conceptions for changing them into scientific concepts (Mortimer, 1995) – moving from concrete,
macroscopic level explanations of the phenomena towards understanding abstract level, which can be described by microscopic and symbolic means.

The process of conceptual change is often facilitated by the usage of conceptual models. Vince & Tiberghien (2002) distinguish four categories that students have to consider while learning with conceptual models – the real everyday situations that they try to explain, the modeled framework of everyday situations, the conceptual theoretical framework (a conceptual model), and the experimental world that resides upon the theories explained by the conceptual model. Both the conceptual and everyday framework models can be expressed either internally or externally. The real world components from this framework cannot be used in the computer environment and students will, thereby, be operating with i) problem situations modeled for them either from everyday or conceptual aspects, ii) conceptual visual or verbal models used for promoting conceptual change, and iii) internal representations of problem situations that learners compose from everyday or conceptual aspects.

A common view about how conceptual change occurs expects that students will either abandon their initial conceptions due to conflicts with scientific concepts or their initial ideas will be integrated into a more powerful scientific ideas (Mortimer, 1995). Going in depth from these simplified explanations, several studies emphasize the importance of cognitive information processing mechanisms during the conceptual change. Derry (1996) describes the construction of mental models as the process of mapping active memory objects onto components of the real world phenomena, then reorganizing and connecting these objects so, that they form together a model of the whole situation. A construction-integration theory developed by Kintsch (1986), gives an explanation that, when learning conceptual knowledge, students may create a new mental model that is a representation of the conceptual model. Comprehension in this framework comprises selective activation of prior knowledge in the context of conceptual model by which the situation model (an enriched version of conceptual model) is built. Vosniadou (2002) has suggested that mental models as the aids of explanation construction can play an important role in conceptual development and conceptual change – they are neither completely determined by data nor theory and can operate like vehicles through which implicit physical knowledge enters the conceptual system. She proposes that the formation of mental models is constrained by prior beliefs and the earlier mental models can act as constraints on the way of new information. According to the mental model revision theory (deLeeuw & Chi, 2003) learning with conceptual models can be seen as the process of repairing the existing domain model (mental model about the learned domain) with the elements from the conceptual model. Learners will be inserting information from conceptual to domain model, replacing wrong knowledge in it with correct information taken from the latter, and they will be repairing the flaws in the existing domain model by inferences of new knowledge that is not taken from conceptual model.

In the perspective of cognitive information processing theories, teaching for conceptual change has to consider which types of representations will be activated during the learning process and how the actual conceptual development takes place. This research aims to explain the processes of conceptual change during conducting different kinds of modeling activities – designing explanation models or exploring through the use of inquiry models – in the collaborative settings.

2. Materials and methods

2.1. Participants

The participants of the study were 53 secondary school students of 2 rural and 2 town schools. These students had different knowledge about genetics – at one school the students had studied the topic in the previous year, at other schools they were not familiar with the topic. The students of each school were randomly divided into groups of 3-7 people who worked at two different settings of the experiment. The online activity was guided virtually by a tutor.

2.2. Learning task

The two group design of the experiment comprised the following activities: introduction of the ‘Case of ladybirds’ from situational context, individual pre-test, collaborative hypothetico-predictive reasoning in synchronous environment Collaborative Virtual Workplace 4.0 (CVW) (http://cvw.mitre.org) without conceptual information, collaborative problem-solving in CVW with the presence of conceptual information and with the possibility of either expressive or exploratory modeling (see Fig. 1), and individual post-test that was conducted the next day. In pre- and post-essays and during the collaborative
tasks the students had to solve the genetic problem: Why might the outside traits of insect generations change if the pesticide was used?

![Figure 1. Whiteboard with template model for expressive modeling (left) and ‘Ghost model’ for exploratory modeling (right).](image)

The groups that worked in expressive learning environment of CVW (see Fig.1, left) had to use a whiteboard with the background image containing a ladybird, the pesticide, and the chromosomes in order to model their problem representation by adding texts and arrows. The groups that worked in the exploratory simulation environment had to apply the analogy principle by using the ‘Ghost model’ (http://mudelid.5dvision.ee/tondid/) that enabled to test the causal effects of different mutagene levels on the appearance and the genes of young and elderly ghosts and their offspring (see Fig.1, right). In both experimental settings students’ learning was facilitated with process scaffolding during hypothetico-predictive reasoning, and with process and conceptual scaffolding during modeling. The conceptual scaffolding prompts were performed according to the similar script and focused on guiding the students towards representing both the objects and processes, as well as considering their concrete and abstract levels of the emergence.

### 2.3. Methods of analysis

For characterizing the changes in students’ conceptual situation models during the learning process, the individual essays before and after the activity, and the individuals’ participatory utterings during two discussion phases, which represented their internal situation models, were used as the basis of analysis. Thus four different representations could be analyzed for each person.

The content analysis of representations enabled to find the common elements towards which the students referred to, while solving the “Case of ladybirds”. The structure of the situation models was found accordingly – all the elements expressed in each student’s situation models were categorized either as concrete entities that were described by the macroscopic level explanations, or as abstract entities that were described by using the microscopic or symbolic level explanations. Next, each student’s situation model was categorized by the extent of the usage of different types of elements. The following hierarchical conceptual categorization was applied for situation models:

1. Concrete: Objects and events are described only at concrete level.
2. Semi-abstract: Objects and events are described mainly at concrete level; the entities described at abstract microscopic level do not belong to the framework of the current problem situation.
3. Concrete-abstract: Objects and events are described both at concrete macroscopic and abstract microscopic levels.
4. Abstract: Objects and events are described only at abstract microscopic level.
5. Meta-abstract: Objects and events are described at concrete macroscopic and/or abstract microscopic, and symbolic levels.

It was investigated by Cross tabulation how the individuals’ situation models changed from one conceptual type to another in the different phases of the activity.
3. Results

The results about the students’ conceptual change were presented as the shift from one category to another at sequential phases of the experiment, comparing the two experimental settings.

It was found that in both the expressive and exploratory learning environment the students advanced similarly expressing more sophisticated problem representations during the hypothetico-predictive discussions than they did in their essays before the activity (see Fig. 3). There was a tendency that those who were at lower ‘Concrete’ or ‘Semi-abstract’ levels of representation tended not to participate in the discussion, whereas the students who appeared to have previously higher ‘Semi-abstract’ or ‘Concrete-abstract’ essays operated at the same or higher level in the discussion.

During the discussions in the expressive and exploratory modeling environment, which followed to the hypothetico-predictive reasoning, the students made one more step further in representing the problem (see Fig. 4). It was found that the students who were working with the whiteboard model were less effective in representing higher order types of explanations than the students who were using the web-based model.

An opposite tendency was recorded after the modeling activity (see Fig. 5). It appeared that the ‘Meta-abstract’ and ‘Abstract’ reasoning in the post-essays was common only for the students who were working in the expressive learning environment. In the exploratory learning setting the students were having more advanced mental models during modeling discussions than in their post-essays after the activity.
4. Discussion

4.1. Mental model development by expressive modeling

Firstly, we aim to explain the process of students’ mental model activation, while performing collaboratively the tasks in expressive modeling setting of the experiment (see Fig. 6).

At the beginning of the activity, when students started to compose the hypothetical solutions, the changes in their mental models were best explained with the construction-integration theory (Kintsch, 1986). The text of problem introduction was used in the light of earlier experience for composing individual situation models (See Fig 6, arrows 1a&b). These mental representations could have been used later during the discussions like moulds restricting the integration of new elements (Vosniadou, 2002) or analogically to mental model revision theory (deLeeuw & Chi, 2003), students could have been revising their individual mental models and making changes in these due to incoming information. It was supposed that when collaborative task was directed towards generating a team solution, the process of changing individual mental representations towards the structure of the shared representations would be favored because the flaws in the individuals’ situation models would be made visible during the discussion. The analysis
conformed that students moved from ‘Concrete’ types of explanation towards ‘Semi-abstract’, ‘Concrete-abstract’ and ‘Abstract’ types, but several flawed situation models remained unchanged (Fig. 3, left).

The meaning of joint modeling of the problem model, during the second step of the activity, was to give the common frame of reference to the students, by visualizing the teams’ mental model, and enhancing, thereby, the creation of wholistic understanding of the situation. We predicted that after students have been introduced to the conceptual framework related to the problem, the internal representations of the situation would be supposedly reviewed in the light of conceptual information presented in the text, and the wrong elements in the situation models, as well as from the joint model on the whiteboard, would be changed (See Fig 6, arrows 2a→2c). Alternatively, if students had not composed the clear situation model yet during the earlier discussion, this might be obtained from the conceptual information, like the construction-integration theory (Kintsch, 1986) suggests. The results of the expressive modeling (Fig. 4, left) tended to support the former explanation – students who had concrete type of representations of the situation did not interact with peers during the modeling discussion, apparently due to the lack of coherent understandings with their peers, whilst students, who formerly had flawed understandings, developed further towards ‘Concrete-abstract’ and ‘Abstract’ explanations. It also appeared that the more conceptually valid students’ situation models were, the better did they develop further conceptually. The importance of collaborative discussions, joint modeling and conceptual scaffolding appeared to be the externalization of team-members’ internal, conceptually enriched, wholistic situation models and the initiation of the discussion that promoted the model revision based on the flaws that were noticed on the team model. To conclude, the process of expressive modeling started with composing enriched situation models on the basis of the text and personal preknowledge. This activity was followed by conceptual revision described by deLeuw and Chi (2003). The collaborative discussion and modeling played key roles in the process of conceptual development triggering cyclical revision processes that might not have been performed individually. Another important element in the collaborative modeling process was conceptual scaffolding that promoted the usage of different levels of explanations in the situation models that the students might not have used on their own initiative.

Was expressive modeling effective from the perspective of individual conceptual change? The comparison of students’ situation representations during expressive modeling discussion with their individual situation models after the activity (Fig. 5, left) revealed a tendency that students were able to reproduce the problem models at comparatively lower level of explanation after the activity than during the discussions. Still, most of the participants appeared to reach conceptually at ‘Concrete-abstract’, ‘Abstract’ or even at ‘Meta-abstract’ levels, expressing in their post-essays the conceptually enriched understanding of the everyday situation of the problem (See Fig 6, arrow 2d).

4.2. Mental model development by exploratory modeling

Secondly, the mental model development is discussed in the context of exploratory setting of the experiment (see Fig. 7). While the mental model development during initial hypothetical-predictive reasoning appeared to follow the previously described pattern of forming the situation models (see Fig. 3, right and Fig 7, arrows 1a&b), the inquiry with simulation model influenced students’ situation models differently than composing the model in expressive setting of the experiment.

Theoretically, if students are working with web-based conceptual model they have to develop its mental representation (see Fig 7, arrow 2a). Next, the internal representation of the situation has to be tested by using that representation of the conceptual model. This procedure can be seen as inserting elements from the representation of the situation to the framework of conceptual mental model (see Fig. 7, arrow 2b) that is the opposite process compared with mental model development during expressive modeling. By controlling the validity of the situation representation with running the conceptual model, the elements of the situation will be evaluated in the light of mental representation of the conceptual model. If the conceptual model is concentrating only on the limited aspects related to the situation, the whole students’ representation of the situation cannot be revised. If students’ internal representation of the conceptual model is imperfect, the changes in the situation model will not improve the conceptual understanding. The first problem could be overcome by appropriate conceptual scaffolding, whereas the collaborative discussions might enhance the development of conceptually correct individual situation models.

Results from the discussion phases of exploratory modeling showed a tendency that during the modeling discussions (Fig. 4, right) many students were operating with mental representations of the conceptual model performing reasoning at ‘Abstract’ and ‘Meta-abstract’ levels that were promoted by
conceptual scaffolding and by the model. This positive tendency appeared to disappear in students’ essays after the activity (Fig. 5, right). It was assumed that this phenomenon could have been explained by the students’ operating with two different mental representations, while performing the exploratory modeling activity – when working with simulation model the mental representation of the conceptual model was activated and students inserted the elements from situation representation into it in order to validate these. This procedure could have inhibited the development of students’ overall conceptual situation model of the problem. When expressing their situation models after the activity, they were unable to reproduce conceptually more advanced representations (see Fig. 7 arrows 2 c&d).

Comparing the mental model development, while performing hypothetico-predictive reasoning tasks, we can conclude that both of the groups started by following construction-integration model but the modeling activities appeared to be performed differently. In expressive modeling setting the situation model in short-term memory was changed towards conceptual one by integrating the elements from the theoretical text that was promoted by conceptual scaffolding. In exploratory modeling setting the situation model was composed and compared with the mental representation of the conceptual model. The learners had to move back and forth between two mental models that were at different levels of abstraction and their task was to construct relations between the proper elements at two mental representations. This made the development of conceptually valid mental models of problems more complicated and students were not able to develop conceptually higher order representations after the exploratory modeling activity.

6. Conclusions

The current paper aimed to analyze two different types of collaborative modeling activities from the perspective of individual conceptual development:

i) Exploratory modeling performed on the whiteboard of the synchronous learning environment.

ii) Expressive modeling performed with the help of web-based simulation models in the combination with collaborative discussions in synchronous environment.

The cognitive information-processing theories about the conceptual development (Kintsch, 1986; Vosniadou, 2002; deLeeuw & Chi, 2003) were applied in explaining the changes in individuals’ mental models. The findings allow us to suppose that expressive modeling will activate students’ mental models differently than the exploratory task with simulation models. In case of expressive modeling students’ initial situation models would be revised by adding new elements from the conceptual materials with the help of peer-discussions and facilitated by the conceptual scaffolding. Exploratory modeling, on the other
hand, demands the activation of two different mental models by students – the internal representations of
the situation and the conceptual model. The students would be validating the elements from the situation
model by holding the mental representation of the conceptual model active in their short-term memory.
When this process was performed only in one direction, from the internal representation of the situation
towards that of the conceptual model the formation of overall conceptually enriched situation model was
inhibited. To overcome this difficulty, students have to be scaffolded towards revising their situation
models also from the perspective of conceptual models. Should this procedure be performed as the back-
and-forth movement between each element of the representation of the situation and the conceptual model,
remains open. It may also be, that the conceptual development would be more enhanced if the elements of
the situation are, firstly, evaluated by mapping them to the conceptual representation that would help to
understand the theoretical simulation models from the perspective of concrete situations’ and, secondly, the
existing representation of the situation would be revised from the perspective of the situated understanding
of the conceptual model.
The main conclusion of the study is the assumption that while designing learning activities and
scaffolding aid to prompt learning, the nature of cognitive information processing caused by different types
of modeling has to be taken into account. In further studies, the in-depth analyzes of modeling should be
directed towards investigating the influence of instruction on students cognitive information processing and
conceptual change.

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