FRAMEWORK FOR SCAFFOLDING THE DEVELOPMENT OF PROBLEM REPRESENTATIONS BY COLLABORATIVE DESIGN

Abstract. For promoting the development of students’ problem representations by collaborative design the learning activity for the network-based synchronous environment Collaborative Virtual Workplace was designed. Two biology and chemistry related problem situations were presented to 21 biology and 18 chemistry class students of different schools. Students’ activity was scaffolded by an online tutor. The analogous problem situation was solved individually in the pre- and post-test. The process of design on whiteboard tool and the textual conversation on chat tool were recorded and the content was analysed from log-files. Based on the individuals’ external problem representations and the interactions recorded on whiteboards, the theoretical framework for the analysis of problem representations in science was created. According to this, the development of students’ problem representations must be supported on the dimensions of the ontological “objects” and “events” category components of mental models at the levels of everyday, scientific and scientific symbolic explanations. It was found that the collaborative modelling activity in the synchronous network environment caused the shift in students’ individual problem representations towards more complete and scientifically valid mental models.

1. INTRODUCTION

One of the goals of science teaching has been promotion of problem solving and decision-making. Effective problem solving requires the construction and coordination of valid problem representations. In this paper we propose the theoretical framework for scaffolding the process of composing collaboratively problem representation models on whiteboard tool in synchronous network-based environment.

The representational systems for a problem can be considered as a set, with some members internal and some external. Internal representations are in the mind as propositions, mental images; external representations are in the world as physical symbols (e.g., written symbols, etc.) or as external rules, constraints, or relations embedded in physical configurations (Zhang, 1991). Internal representations or mental models are the basic structure of cognition in representing objects, states of affairs, sequences of events, the way world is, and the social and psychological actions of daily life (Johnson-Laird, 1983; Norman, 1993). Mental models possess representations of objects or events in systems and the structural relationships between those objects and events (Jonassen, 1995). It has been supposed that for building the mental models there are two cognitive subsystems – one specialized for the representation and processing nonverbal objects/events (i.e., imagery), and the other specialized for dealing with language (Paivio, 1986).
While structuring the world, it is possible to categorize all the entities into three primary ontological categories: “matter” (natural objects and artefacts); “events” (processes, events, systems and constraint based interactions) and “abstractions” (mental states) (Chi, 1992; Chi et al., 1994; Chi, 1997). Linked with material substances and events, different types of properties or ontological attributes are perceived. Comparing the ontological categories of matter and events (Chi, 1992) with the elements of mental models (Jonassen, 1995) it can be concluded that if a person observes the world he develops a mental model of ontological objects and events categories with their properties and relationships. Novices seem to be inclined toward materialistic or “substance based” conceptions (Reiner et al., 2000) and surface features of the problem under the constraint of the ontological category (Slotta et al., 1995). In the complete mental models of phenomena both the objects and events categories should be represented. Running the mental model should result in registering changes of objects’ properties and relationships due to the events happening. In order to understand the problem situations, a person has to build the relationship between the object and event ontological categories in its mental model, moving flexibly between the object and event categories and registering the properties and relationships related to these.

According to the conceptual change model, teaching is the process of dealing with students’ conceptions and changing them into scientific ones (Mortimer, 1995). The second barrier in constructing valid internal problem representations, thereby, resides at the levels of how the ontological categories of objects and events are modelled in persons’ mental representation. While constructing mental models not only the information from the outside real world situation is used. Derry (1996) describes it as the process of mapping the active memory objects onto components of real world phenomenon, then reorganising and connecting these objects so, that they form together a model of the whole situation. One of the frameworks originally proposed for chemistry describes the levels of understanding science at macroscopic, microscopic and symbolic levels (Johnstone, 1991). The macroscopic level is sensory and deals with tangible and visible objects and phenomena with their properties; the microscopic level involves with objects and processes at particulate level; the symbolic level represents objects and processes in terms of formulas and equations. These levels can be related to the everyday explanations and scientific explanations. It was supposed that for registering the state of students’ problem representations the ontological categories of objects and processes (Chi, 1992; Chi et al., 1994; Chi, 1997) and also the levels of everyday, scientific narrative and scientific symbolic reasoning should be combined.

The shift from simpler problem representations to complex ones has more often been explained as an event that occurs only in the mind of an individual. On the other hand, it is also the socially mediated process where the learners’ mental models about the representations of the world are changed by new experiences, participating in learning activities, etc. Scaffolding the development of scientifically valid problem representations is one of the crucial activities in teaching science. The majority of the strategies of teaching as a conceptual change are related to the expectation that students’ initial ideas should be abandoned or subsumed in the teaching process (Mortimer, 1995). On the other hand, the possibility of the
coexistence of two meanings for the same concept, which are assessed in the appropriate context has been demonstrated (Chi, 1992). This raises the question of the ideal structure of the mental representation that the students should run in their head. In the current framework, it was presumed that the students should be scaffolded to build their mental representations in two dimensions – firstly, by recognising the “objects” and “events” categories with their causal relationships, and secondly, by distinguishing the “objects’ properties before and after the event” and the “event properties during the event” at different simultaneous reasoning levels.

In order to observe and scaffold the changes taking place in learners’ mental representations these should be externally expressed. External representations can be defined as states of the physical world deliberately created as a part of cognitive process, rather than for pragmatic ends (Zhang & Norman, 1994). One of the possibilities for accomplishing it is to use the design activity. Designing refers not only to the activities of producing artefacts, but also to the process of arranging elements to form systems (Roth, 2001). Designing can be used for collaboratively developing external problem representations in science. These express the objects and events ontological categories with their properties and the structural and causal relationships between the elements of the model. By design activity the students’ individual internal mental models are turned external on the shared modelling area. The collaborative designing effort can bring forth the development of more complete mental model representations. Students whose individual mental models are at different levels of scientific explanation and who might not have a full picture of the ontological categories will be complementing each other and the design product – the competent multi-level external problem representation – is formed. The process of designing collaboratively does not eliminate non-scientific explanation but will improve the less sophisticated mental representations with new ontological categories and help to build bridges between objects and events at the different reasoning levels.

For effective designing of collaborative problem models the synchronous network environment can be used. Text-based chat room and whiteboard for visual mental representations serve as flexible tools for sharing the mental models. The representation tools mediate collaborative learning interactions by providing learners with the means to express their emerging knowledge in a persistent medium, inspectable by all participants, where the knowledge then becomes a part of the shared context (Suthers & Hundhausen, 2001). In the network environment the learners can be assisted to build new knowledge structures with the help of the tutor who models the desired learning strategy or task and then gradually shifts responsibility to the students; by the advanced peers who help the less sophisticated students in the learning process; or by the instructional materials that support the learners (Pressley et al., 1996). Based on this theoretical framework, one of the goals of the current study was to investigate the possibility for promoting the shift towards scientifically valid problem representations by collaborative design in network-based synchronous environment. The main research questions of our study were: How are the shared problem representations composed during the collaborative design activity without content-scaffolding of the tutor? How does the collaborative design activity in synchronous network environment develop individuals’ problem
representations? What is the appropriate model on which the scaffolding of the development of problem representations should be based on?

2. DESIGN

For promoting the development of students’ problem representations by collaborative design the learning activity for the network-based synchronous environment Collaborative Virtual Workplace 4.0 (CVW) (http://cvw.mitre.org) was developed. Two biology and chemistry related problem situations were presented to different groups of learners during synchronous lessons. The problem topics were based on the knowledge previously studied by these students in science lessons. Students had to design collaboratively the problem representation models on the whiteboard tool in the CVW environment, while the tutor performed only process scaffolding. Before and after the collaborative activity the same problem situation was solved individually and the external problem representation models of the individuals were compared. The process of composing the collaborative problem representation models and the textual conversations between the participants and the tutor were recorded by system and analysed. Based on content analysis of the individuals’ external problem representations and the recordings of whiteboards, the theoretical framework for the analysis of problem representations in science was composed. This served as a tool for analysis of students’ development and the basis for performing content scaffolding in future design activities.

2.1. Participants

The participants of the study were 39 students from Estonian secondary schools, 21 9th grade biology students and 18 10th grade chemistry students (21 males, 18 females, aged 15-17). In the CVW environment 2 lessons about biology problem and 2 lessons with chemistry problem were performed by different groups of students. The size of collaboratively working groups was 2-3 in the first phase of the activity and 5-8 in the second phase. All the groups were scaffolded online by the same tutor, who was the researcher of the current study.

2.2. Materials and the tasks

Two problem situations — the cases of “Biologically modified food” and “The sunken ship” — were presented to the students on the web pages. The situation from everyday life was described in the format of text and pictures. The problems: “Is it safe to eat genetically modified tomatoes?” and “Why were some objects near the sunken ship more deformed than the others?” were raised from the topics. The students were asked to solve the problem individually by composing the explanatory picture using text and symbols. For this designing activity they were supported with worksheets that had already the pictures of three objects that the text of the problem situation had described (gene – tomato – mans’ digestive system with body contours; or golden ring – tin can with traces of rusting – pail with traces of rusting).
The following activity in the synchronous environment was collaborative involving the elements of jigsaw. In the first phase, the students were divided into groups between three virtual rooms of the CVW environment. In each room a different additional material, explaining some aspects of the problem from the scientific viewpoint, was presented as a link to the web page. The tutor followed the flexible script of scaffolding the pilot lessons by offering only process, functional and interpersonal scaffolding because it was unpredictable how the students would actually perform during the collaborative process of designing the shared problem representations. The students in each room had to read the additional material and work together on the shared whiteboard tool designing the explanatory picture of the problem situation. Three objects from the problem situation were presented as the template model on the initial whiteboards. The whiteboard of CVW environment enabled simultaneous work of all the participants. In the second phase, the students from three different virtual rooms were re-grouped by the tutor into the teams of mixed membership. In each group the members from three previous groups were to be represented. The task was to solve the problem once again designing the final explanatory picture using the template model on the whiteboard. After the design activity in synchronous environment the problem was once again individually presented to the students and they had to modify the template picture on worksheet composing their final problem representation.

2.3. Analysis

For the analysis of students’ individual and shared external problem representations the recordings of the design activity on whiteboard and the individual worksheets with explanatory problem models were used. The process of complementing the shared problem representations on whiteboard was followed step-by-step and the sequence of adding the elements to the external representation was recorded. The individual and shared explanatory models of the problem were analysed according to the ontological categories of objects and events and the levels of everyday and scientific explanations. Based on the preliminary content analysis the theoretical framework for the analysis of problem representation in teaching science was formed (Fig 1).

According to this, the problem representation can be modelled as the matrix onto which the ontological objects and events can be mapped. The categories of “objects before the event with their properties” and “objects after the event with their properties” form the ontological objects level in the two bottom squares of the matrix. The category of “event with its properties” forms the ontological events level on the upper part of the matrix. It is possible to express the objects and events categories on each of these parts of the matrix as picture-like or language-like representations (Paivio, 1986) at the levels of everyday explanations (language-like or picture-like), scientific narrative explanations (language-like) and scientific symbolic explanations (picture-like). These are analogous with the macroscopic, microscopic and symbolic levels proposed by Johnstone (1991). Using this framework, the development of students’ problem representations can be recorded in
the dimensions of the components of the mental model and in the dimension of everyday, scientific narrative and scientific symbolic explanations.

![Theoretical framework for the analysis of problem representations](image)

**Figure 1. Theoretical framework for the analysis of problem representations**

This framework for multi-level problem representations was used for mapping the structure of students’ individual problem representations before and after the pilot lesson. Accordingly, the individuals’ problem representations on worksheets were categorised to: objects and properties before the events (no explanation, everyday explanation, scientific explanation); objects and properties after the events (no explanation, everyday explanation, scientific explanation) and events with their properties (no explanation, everyday explanation, scientific explanation). The significant shifts in students’ problem representation development were recorded by McNemar's Chi Square analysis.

### 3. RESULTS AND THE DISCUSSION

The first problem under investigation was how the shared problem representations are composed during the collaborative design activity without the content-scaffolding of the tutor. After reading the problem situation and the additional information about the problem the students were guided to complement the model templates with new elements. The model template in biology presented all the main objects concerning the problem situation, but the model template in chemistry had one imaginary object – seawater – that surrounded visible objects. This difference started to influence the design models of problem representations – on the models of biology, it was possible to show the process and structural relationships between the objects with picture like symbols (arrows, lines), on the models of chemistry it was
more complicated and the arrows were practically not used. It was found that most of the teams tended to follow a certain sequence during the construction of biology problem representations, starting from adding the arrows between the objects, then labelling the objects with names (gene, tomato, etc.) and next order, completing the objects with property descriptions (genetically modified tomato). Finally, the event descriptions were added to the arrows (man is changing the genes; genes from modified tomatoes will be digested, etc.). The same sequence of labelling and describing the objects first order was followed also in the lessons of the chemistry problem. This sequence can be one of the evidences that the construction of internal problem representations starts from defining the preliminary structural relationships between objects, next the objects’ ontological category is characterised and last order the events ontological category is elaborated.

The problem of genetically modified food enabled students to express their problem representations only at everyday explanation and scientific explanation levels, leaving out the scientific symbolic. In order to solve the problem of chemistry, the students had to do reasoning at more abstract levels. It appeared that in the first phase the students often used mainly the everyday explanations for the macroscopic level objects and events (the can has rusted, iron started to disappear), but in the second phase of the activity the scientific narrative and scientific symbolic levels appeared among the everyday explanations. This supported the initial prediction that the collaborative problem representation model would be at multi-level of reasoning. Comparing the team models in the first and second phases it appeared that the second models were more complete in comparison with the theoretical framework model. The models designed during the first phase of the activity were built by taking account parts of individual internal problem representations and complementing the shared models with new elements that had been taken from additional scientific information presented on the web page. Designing the second problem representation the students transferred both the elements from the previous teams’ models that did not appear to be on their individual design models, and also they used the elements from their individual models that were not used on their first team models.

It appeared that some team models were built collaboratively – the participants used the previously added elements for expressing their own ideas and the unnecessary arrows, and the remarks made by other members were deleted. The final model of those teams explained the problem situation and could be used for finding the solution. Opposite to this, there were also groups that worked on the shared modelling area as individual members. On such design models, the elements were doubled and each member had elaborated their own ideas on the same design model. While composing the models, the students used the whiteboard area also for content-related discussions. On some models these were deleted in the end, but on others the team-members’ different converse opinions were retained showing that the students had not reached to the mutually accepted decisions. It can be concluded that in the process of composing the scientifically valid shared external problem representations the effective information-embedded scaffolding that supports students with scientific information according to the problem representation framework; the effective process-scaffolding initiating collaborative team-work; and
Performing the collaborative activity in synchronous network environment is motivated only if it is developing the individuals who are participating in it. Therefore, it was studied how the collaborative design activity changed the individuals’ problem representations. It was examined at what levels (no explanation, everyday explanation, scientific explanation) the students represented the objects with properties before and after the events, and the events with their properties in their external problem representation models (Table 1).

Firstly, it was found that there was a big difference of what has been represented on the models of biology and chemistry. It appeared that in biology the “objects and its properties before the event” category was seldom described and the students concentrated on the “event and its properties” ontological category. The post-test appeared to describe more often the “objects after the event” category. On the problem representation models in chemistry the main emphasis was on describing the two categories of “objects properties before and after the events” and the “event” ontological category was less used and emerged more often in the students’ post-tests. In the problem representations of both biology and chemistry the students started to use scientific terminology more often (e.g. eating modified tomatoes can cause diseases – genes are digested in the man’s digestive system, but sometimes they can cause allergy, can consists of tin and iron – tin and iron form a galvanic pair). The general shifts between pre- and post-tests of students’ individual mental representations also appeared to reflect some of the crucial elements that were important for solving these problems correctly. In the case of “Biologically modified food” more students were able to conclude in the post-tests that the process of genetic modification is deliberately carried out by men (p=0.063) in order to increase the quality of tomatoes and that genetic modification does not transform...
only the appearance of the food but also the sequence of its DNA (p=0.092) and that this new protein can cause allergy (p=0.109). The significance levels of the changes on biology problem representations were lower than in chemistry. Supposedly it was caused both by the nature of the problem and the less scientific reasoning habit that was characteristic to the biology subject. The changes in the students’ problem representations appeared to be more significant in the case of “Sunken ship”. Most of the students did not mention the presence of seawater and its influence to the objects in their pre-tests. However, on the models designed after the collaborative activity the chemical elements in seawater increasing the velocity of corrosion were mentioned more often (p=0.001) and the presence of electrolyte in reactions (p=0.004) was described. It can be concluded that both in biology and chemistry problem representations the students’ mental models changed towards being more complete in describing ontological categories of objects and events at more scientific level. This shift was caused by the collaborative modelling activity performed in the synchronous network environment.

4. CONCLUSIONS

This study was initiated by the need of finding the applicable framework for scaffolding the process of collaborative design activities in synchronous network environment. The lessons using textual chat and whiteboard tools in the synchronous environment and the analysis of students’ individual and shared problem representations before, during and after the activity enabled to develop the theoretical framework for analysing problem representations in science and planning the scaffolding interactions for the future activities. The framework for problem representations should also be used for designing supportive materials for the problem-solving events. The development of students’ problem representations must be supported in the dimensions of the ontological “objects” and “events” category components of mental models at the levels of everyday, scientific narrative and scientific symbolic explanations.

The lessons with biology and chemistry problems demonstrated that the construction of shared problem representations started from defining the preliminary structural relationships between objects, next the objects’ ontological category was characterised and only at last the events ontological category was elaborated. It appeared that the problem representations of biology and chemistry differed by the usage of ontological “objects” and “events” levels – in biology the students concentrated more on “events” category but in chemistry the emphasise was on the two “objects” categories. In the problem representations of both biology and chemistry the students started to use scientific terminology more often. It was also demonstrated that the collaborative modelling activity performed in the synchronous network environment caused the shift in students’ individual problem representations towards more complete and scientifically valid mental models.
This research was supported by the Estonian Science Foundation grant No. 4473. We express our appreciation for the cooperation and assistance of the Estonian science teachers of the in-service course of “Computer-based visualization in science” 2001-2002. The helpful comments of assoc. prof. Eve Kikas and prof. Jean-François Le Maréchal are also acknowledged.

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