Evaluating the use of qualitative reasoning models by secondary school teachers

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Abstract

The present work describes an interdisciplinary evaluation activity of learning by modelling involving secondary school teachers. DynaLearn software functionalities (www.dynalearn.eu) were presented to teachers in a course. They created their own models integrating knowledge from different areas by developing interdisciplinary projects. During the course, the teachers discussed difficulties and facilities found during the modelling activities; aspects related to motivation and support in the context of the teacher–student interaction; how the software can be brought into the classroom; and educational activities that could be developed in their disciplines. The results suggest an improvement in the identification of causal inferences after modelling activities performed by the secondary school teachers. The teachers were positively motivated to explore models, to engage in a modelling activity and to learn more about the phenomena being studied with DynaLearn support. Initiatives of this type may become the basis for preparing teachers to work out scientific concepts with the support of QR models.

1 Introduction

Teaching must not be merely support memorization of facts, but also to develop understanding of processes in a creative way, by integrating the students' previous knowledge [Bredeweg and Forbus, 2003]. In this context, models may facilitate the learning process, because the contents are transmitted objectively, and in the perspective of being tested and explored [Barab *et al.*, 2000; Clement, 2000; Borges, 2002; Ferreira, 2006]. Model building and exploraion allow students and teachers to see the complexity of the phenomena being learned, including their nuances and uncertainties [Ferreira and Justi, 2008].

The utilization of models is a constructive process of knowledge [Bredeweg and Forbus, 2003; Forbus *et al.*, 2001; Salles and Bredeweg, 2001; Salles and Bredeweg, 2003; Nuttle and Bouwer, 2009]. The use of computational tools allows the construction and handling of models, what surpasses the simple activity of observing phenomena [Vosniadou, 2002]. This way, modelling raises a new tool to teaching in schools [Justi and Gilbert, 2002].

The role of teachers as intermediaries in the model construction process should not be authoritative, but questionable, conductive and creative [Ferreira and Justi, 2008]. Textbooks (classic literature) coupled with the qualitative conceptual modelling help teachers during the formulation of their lessons, especially those related to complex phenomena [Dresner and Elser, 2009].

By conducting qualitative modelling exercises, prior to their classes, teachers allow the concepts to be understood and peer discussed. This approach may improve learner's self-monitoring and/or metacognition capabilities [Bredeweg and Forbus, 2003; Dresner and Elser, 2009].

This study was designed to motivate teachers to use qualitative modelling on the development of competences and skills of secondary school students. The target competences include:

- Understanding natural phenomena; mastering natural and modelling languages, and mastering the capability to translate among different languages;
- Identifying central and peripheral information, presented in different contexts (texts, literature, models);
- Comparing possible solutions for a problem;
- Formulating and articulating adequate and consistent argumentation, integrating knowledge from different areas by developing interdisciplinary projects;
- Applying adequate methods for problem analysis, formulation of suitable solutions, selecting and implementing an optimal solution, integrating knowledge from different areas by developing interdisciplinary projects.

Learning activities were performed using the DynaLearn qualitative modelling environment to answer the following questions:

1) What are the teachers' perceptions of the software, the modelling activities and the use of qualitative models in their learning process?

2) Are the teachers motivated to work with qualitative models and to use DynaLearn software?

2 Methodological Aspects of Evaluation

2.1 DynaLearn Interactive Learning Environment (ILE)

The DynaLearn project (www.DynaLearn.eu) is responsible for developing and testing the functionalities of the DynaLearn Interactive Learning Environment (ILE) [Bredeweg *et al.*, 2009], that is specifically created for students to develop their conceptual knowledge of systems. The DynaLearn ILE offers diagrammatic presentations for learners to construct their ideas, and test these by running simulations [Liem *et al.*, 2010]. DynaLearn integrates three different technologies: Conceptual Modelling (CM) based on Qualitative Reasoning (QR); Semantic Technology (ST) to provide feedback and recommendations to learners; and Virtual Characters (VC) to mediate the communicative interaction to learners [Bredeweg *et al.*, 2010].

DynaLearn provides different modelling interfaces, with different sets of modelling primitives, for users to develop models at different levels of complexity. The software permits users to build models ranging from traditional concept maps, through formalised representations of systems structures and basic notions of causal relations, to qualitative models making use of hierarchies and reusable knowledge fragments [Noble *et al.*, 2010]. The six modelling interfaces (Learning Spaces, LS), are listed as follows: Concept Map (LS1), Basic causal model (LS2), Causal model with state graph (LS3), Causal differentiation (LS4), Conditional knowledge (LS5), and Reusable knowledge (LS6).

2.2 Teachers' experience with software usage

Most of the teachers who attended the course had never used or experienced a modelling software. Their experience was mainly related to word processors and internet browsers, and a few of them used programs with mathematical functions, image and video processing and molecular models. They agreed that friendly and easy to use educational software that supports constructivist learning, where they could develop scientific knowledge and provide autonomous learning, would be a powerful tool to teach their students.

2.3 Course framework

The evaluation work was conducted during a course applied in a public secondary school, at Sobradinho, Federal District, Brazil, in June 2010, using the school's informatics lab. At first, one of the authors of this paper (PS) made a preliminary talk to 41 teachers and presented DynaLearn. Next 23 teachers, of different disciplines, showed up as volunteers in the first lesson. The course was distributed in a sequence of 4 classes, 3 hours each, with expositive lectures, model exploration and model building activities (Table 1). As the tools related to ST and VC were not available at that time, the course focussed on conceptual modelling.

The software and CM functionalities were presented during the course they had an overview of the LS1-6. However, practical activities exploring models given by the researchers and further developing their own models were done in LS 1-4, particularly in LS1 and LS2 [Salles *et al.*, 2011].

During the course, teachers discussed impressions obtained from modelling activities on DynaLearn; aspects related to motivation on software use and support, under the context of the teacher – student interaction; how the software can be brought into the classroom; and educational activities that could be developed in their disciplines.

2.4 Modelling activities

Modelling activities explored the lake as an ecosystem; land use: the dilemma between use and conservation of natural resources; specific topics in physics (velocity, acceleration); chemistry (Daniell's battery); environmental science (tourism and the environment); and the biological and social causes of violence (interdisciplinary). A collaborative modelling-mode was adopted, in which the teachers worked in pairs .

Table 1. Activities developed in each class.

Activities	Learning space
1st) Modelling and model: concept map; basic causal model.	LS1, LS2
2nd) Exercises with basic causal model.	LS2
3rd) Causal model with state-graph; causal differentiation model.	LS3, LS4
4th) Interdisciplinary work using DynaLearn.	LS2

2.4 Design of Data Collection and Statistical analysis

To evaluate the teachers' modelling experience in DynaLearn and reasoning about the issues proposed in the course, we applied a pre and a post-test about causality. The pre-test was based on the identification of pairs of causes and consequences of soil loss in a text about "The environmental problem of hydrological erosion". The post-test was applied at the end of the course, after all the modelling activities, and, in a similar way, explored the same text described above.

The number of occurrences of causes and consequences mentioned in the text correctly identified was counted both in the pre-test and the post-test. The results were compared and submitted to statistical analysis. Data were tested for normality and the paired-test was used, as well as the paired t-Test with bootstrapping method running 1.000 randomizations. Tests were run in R 2.12.0 [R Development Core Team, 2010], at the significance level of 5%.

Two likert-type questionnaires, with five possible answers in each question, were applied in order to capture the general opinion concerning the modelling activities and the motivation of teachers to use the DynaLearn software. Examples of the questions are presented in Table 2.

Table 2. Examples of questions in likert-type questionnaire applied to teachers after the course activities.

Questions	Possible answers
What is your general opinion about the course and learning activity we had together?	Very good, good, neutral, bad, vary bad
What is your general opinion about the modelling witch you used to develop this educational activity?	Very hard, hard, neutral, easy, very easy
Which Learning Space did contribute most your understanding of the concepts represented in the model?	LS4, LS3, LS2, LS1
Modelling with the software opened up new ways of thinking about the natural system.	Totally agree, agree, neutral, disagree, totally disagree
I found identifying and extracting the relevant and key information from the text	Very easy, easy, easy/hard in part, hard, very hard

3 Results

3.1 Modelling activities

During the course the teachers were asked to build models about different themes. Initially, they built conceptual maps using DynaLearn Learning Space 1. In one of the activities they had to represent general aspects of a lake ecosystem (Fig. 1). They succeeded in doing that, and the next step was passing from Learning Space 1 to Learning Space 2 in DynaLearn. This step is very important because here they had to build a causal model based on the information represented in their conceptual maps and find out the causal relationships, the entities, the quantities (variables) and the nature of causal dependencies (positive or negative). Some teachers had difficulties to build these causal models, but for most of them it was not difficult. In the first case the teachers just made another conceptual map (Fig. 2), instead to enrich the model by representing also causal dependencies and quantities (Fig. 3). Indeed, as a teacher said "*the way that the models are represented is very important*".

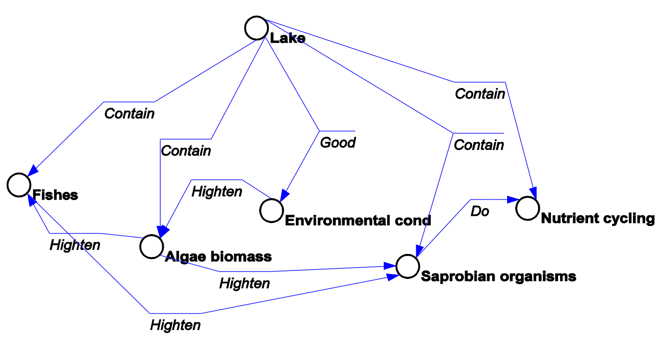

Fig. 1. Conceptual map of "lake as an ecosystem" built by a pair of teachers using Learning Space 1.

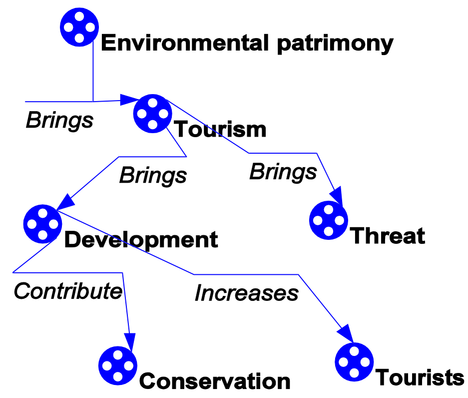

Fig. 2. Model built by a pair of teachers in Learning Space 2, aiming at representing a causal model including quantities and causal dependencies.

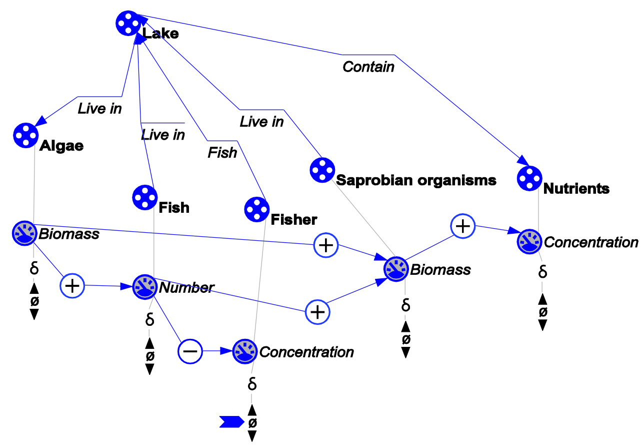

Fig. 3. Model was built by the same teachers that built the model presented in Fig. 1, showing a good transition from conceptual map to causal model.

The transition between conceptual maps to causal models seemed to be gradual because in the causal models the teachers were more worried about the structure rather than the causal relations and the behaviour of the system.

This is clear in models in which the number of entities and configurations is much greater than the number of quantities and causal dependencies, the real responsible for the systems' behaviour.

Another important observation is that some models presented more than one causal chain, what it is very uncommon to way of representation, as seen in Fig. 4.

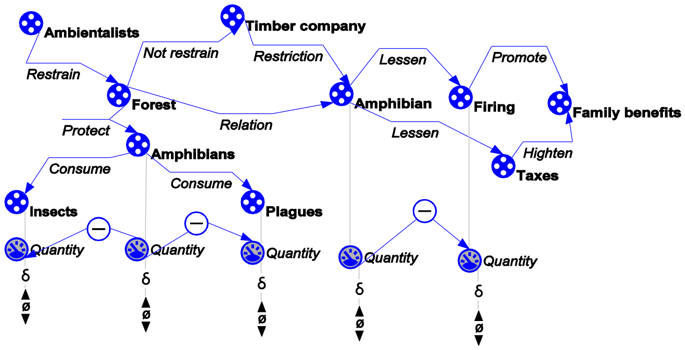

Fig. 4. This model is focusing on the structure of the system (entities and configurations) and on an unconnected causal chain.

3.2 Tests about causality

Only 7 teachers answered both pre and post-tests and the questionnaires. The teachers read a text and identified in it the pairs of causes and consequences of soil loss as described in the text in two moments: before and after the activities. The paired t-Test with bootstrapping revealed a significant difference on the *p*-value ($t = -8.39$; $p < 0.001$; $N=7$). These results suggest the difference between the scores of pre and post-test, as a consequence of an improvement in the identification of causal inferences after modelling activities performed by the secondary school teachers.

3.3 The likert-type questionnaires

In this section we summarized the overall results obtained from the likert-type questionnaires. The questions were classified in nine main topics as follow.

Software usability
In general the teachers liked the learning activities and the course. The number of teachers who found the experience of working with DynaLearn interest was greater (50%), but almost equivalent of that who found it boring (38%). The software was not seen as very hard to use. This is important for bringing the software to schools / classroom. We expect that the implementation and use of new features of DynaLearn software, like Virtual Characters and the Semantic Technology, can change the opinion of those teachers who found the activities or the use of the software to be boring.

Systems thinking
The teachers often mentioned that DynaLearn opened up new and different ways of thinking about natural systems. Some of them mentioned new insights they had while using DynaLearn for systems analysis, and also for the phenomena in study, indeed, having interesting properties for a new learning tool.

Modelling language
Most of the teachers found the modelling language to be easy/hard, specially when they had to be get acquainted with the language, i.e. to be able to recognize and differentiate modelling ingredients and primitives, such as entities and quantities (43% found easy/hard in part), the basis for representing the system structure in the model. The same difficulty was observed, in the way that the quantity spaces qualitatively describe quantities and quantity behavior (63% found easy/hard in part).

Causality
Identifying and representing causality is a central issue for building / exploring qualitative conceptual models. The core distinction has to be made between direct influences and qualitative proportionalities and the opinions of the teachers found easy/hard in part (50%).

Learning spaces
Most of the teachers pointed out LS2 (63% of the teachers) as the richest LS to their understanding of the concepts presented in a model, and 75% of the teachers found important to build models in different specific Learning Space of DynaLearn. It is important to note that teachers had contact only from LS1 to LS4, mainly LS1 to LS3, because their experience with LS4 was very short.

Understanding concepts
Most of the teachers recognized an increase in their understanding of concepts after using DynaLearn and conceptual models. Understanding the complexity of ecological systems and the potential systems' behaviour were mentioned as well.

Modelling approach
The teachers clearly understood the modelling approach and goals, but most found it hard to work with. These are important opinions for considerations about how would the acceptance of this approach be at the schools.

Application of the modelling language and the software
Most teachers considered easy and between easy and hard identifying and extracting key information from texts or other sources, and using the software in other learning topics.

Motivation
The teachers, in general, were positive about being motivated to build a model, to engage in a modelling activity and to learn more about the phenomena being studied with DynaLearn support.

3.4 Open questions about motivation

The teachers appreciated "*the software, the modelling process, the thinking in how to model*", just like one of them said. This positive view came from the idea of causality represented in the models, and the potential they recognized for DynaLearn use in classroom: "*I appreciated how Dynalearn represents the causal relation between entities of the text. It was interesting seeing the link that the software does with modelling and the Novak' concepts*".

Modelling, as an educational goal "*will certainly produce results from the use, especially in subjects as Biology, Chemistry and Physics, in the study of chemical and biological phenomena*". The software was able to produce a reflection in the way of teaching: "*The new way of presenting the concepts to the students, making us rethink the learning process.*"

One of the teachers suggested that the software could be improved if developers could create means for "*placing a progressive modelling and teaching order to DynaLearn based-lessons*". They complained about the short time available for learning and interacting with DynaLearn. "*Time was very short. It was necessary to detail more the tools and the modelling.*" They would like to have "*more time for explanation, more practice for insertion in the learning process of each knowledge area.*"

4 Discussion

The teachers had a very positive view of DynaLearn and recognized its potential for improving the way they teach science and other disciplines. The possibility of exploring causal relations was seen as an important feature. Analysis of the pre and post-tests detected an increase in the average score in post-test greater than in pre-test, which means that the teachers can recognize more causal relationships after modelling activities. These are similar results obtained by [Nuttle and Bouwer, 2009], that the interaction with qualitative models, following the progressive learning route, supports the learning process [Salles and Bredeweg, 2001] and in this study the complexity of modelling tasks increased from Learning Space 1 to 4 what has some similarity with progressive learning route approach. It was observed that the transition of building conceptual maps to more complex models is gradual because in the causal models teachers were still more concerned about structure than causal relations and the behaviour of the system. This was observed in models in which the number of entities and configurations was much greater than the number of quantities and causal dependencies.

Two groups evaluated by [Salles and Bredeweg, 2003], with students with different experiences, from different universities, also agree that modelling effort enhances the comprehension of ecological issues, as well as optimize the learning of complex systems. Other similar result was obtained in an experimental study by [van Borkulo, 2009] comparing two conditions: a group who followed a traditional approach in learning about global warming, and a group who followed an inquiry modelling approach, and the authors found differences between the two conditions with respect to the complex items with better scores for the last group.

During the activities with the software, the teachers were able to identify central and peripheral information, presented in different contexts; to integrate knowledge from diverse areas and understanding natural phenomena; and to compare possible solutions for a problem, i.e. the ability to solve problems using different strategies. Answers to the questionnaires confirm their interest in DynaLearn, as a tool that enhanced their understanding of environmental issues. This is probably related to diagrammatic approach, the capacity to make predictions and to observe systems behaviour as a whole.

A similar result, regarding conceptual modelling was obtained by [Bredeweg *et al.*, 2007]. Their results support the hypothesis that people can learn conceptual knowledge through observing and inspecting qualitative simulations. Positive effects mentioned by studies include simulation models as a useful scaffolding tool to understand complex systems [Nuttle and Bouwer, 2009; Salles and Bredeweg, 2003].

In their work [Dresner and Elser, 2009] made an experiment in which teachers' understanding about ecological complexity, diversity, and experimentation were documented by their models, their essays, through interviews with program staff, content tests and by using a pre-post-test design. Before designing their own conceptual models, participants learned the symbolic language of qualitative models.

As results the authors observed that the use of qualitative models enabled participants to express some of the causal relationships operating in an ecological experiment, thus helping them view their own progression of understanding.

They moved away from their initial intuitive explanation, with misconceptions, to the development of a more complex and accurate understanding of ecological phenomenon. An important remark made by [Dresner and Elser, 2009] was that their results illustrate shifts in teachers' thinking.

One of the teachers made a remark about the impact DynaLearn and learning by modelling potentially can bring to the secondary school: "*A new way of presenting the concepts to the students, making us rethink the learning process.*"

Ongoing work in the same school with the same teachers is being conducted in order to bring them close to the modelling environment, to improve their modelling practice, to apply it in their classes and also to explore the new features of DynaLearn software such as the Semantic Technology and the Virtual Characters.

5 Conclusions

Modelling activities using DynaLearn produced positive effects on learning scientific concepts and improving inferential reasoning skills. This research showed the qualitative modelling was effective in education activities applied to teachers from different domains of knowledge, motivating them to use DynaLearn as a tool for learning concepts. Initiatives of this type may become the basis for the formation of teachers who teaches scientific concepts with the support of QR models.

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