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FROM CONCEPT MAPS TO CONCEPTUAL MODELS – SUPPORTING STUDENTS' UNDERSTANDING OF COMPLEX SYSTEMS[1]

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Abstract. This paper describes a pedagogical approach aiming to support students' understanding of the structural and behavioural features of complex systems. The pedagogical approach is based on the gradual progression from concept mapping to conceptual modelling of systems. Studies conducted aimed to unveil students' conceptual understanding and development of a systems worldview. Instruments and scoring guides were developed for analysing both concepts maps and qualitative computer-models constructed by the students. Results show that the integrated approach supported junior-high-school students' understanding of the structural as well as the dynamic features of systems, and their ability to explore system behaviours under changing conditions.

1 Introduction

Understanding the structural and behavioural aspects of complex systems has become a challenging intellectual endeavour for scientists and science students (Jacobson & Wilensky, 2006). The development of system-related theories and methods since the early years of the 20th century marked a shift in perspective that enabled scientists to study phenomena and processes in the world, focusing on aspects, interrelationships and processes that were overlooked by traditional science. The new theoretical apparatus, complemented by the development of sophisticated computer tools, is a powerful means used by scientists today to “dive into complexity” (Resnick & Wilensky, 1998). From the educational perspective, the “acculturation” of these novel approaches, methods and tools into educational practice is not trivial. The systems approach implies a new way of thinking and represents a serious learning challenge for many students. Some of this knowledge and thinking may appear epistemologically counterintuitive and even incongruent with the approaches, assumptions and practices that characterize the way students learn science with curricula prevalent in educational systems. Hence the demand for the development of new pedagogical approaches and learning environments supporting the growth of a systems worldview and the acquisition of system thinking skills. In this paper we describe such a pedagogical approach integrating concept-mapping and conceptual-modelling tasks. We also present the results of a study following the implementation of this approach with junior-high-school students learning about a marine ecological system.

2 Background

Concept mapping has been developed by Novak in the early 1970's and implemented since then in education for a wide range of purposes (e.g., research, instruction, assessment). Concept mapping is used for different purposes in the science class: for categorization and organization of concepts, for representing hierarchical relationships, for presenting interrelationships among concepts. Concept maps are also used as assessment tools for capturing the mental models learners use when constructing them.

So far, the focus of most analysis schemes of concept maps (Novak and Gowin, 1984; Kinchin & Hay, 2000) was on the structural and static aspects of the represented system. This approach has been criticized as one that ignores the dynamic aspects of complex systems (Safayemi, Derventseva & Cañas, 2005). Hence the crucial role that other modelling tools might play in support of students' understanding of the dynamic aspects of complex systems. These tools are in use in the "Learning by Modelling" pedagogical approach. In this approach, students are allowed to construct models of systems and run simulations - for observing and exploring systems' behaviours under changing conditions.

Different approaches toward learning by modelling were developed - the one adopted in our studies argues for the value of qualitative modelling (QM) for learning (Bredeweg & Forbus, 2003). The educational QM computer tool used in our studies is "DynaLearn" (Bredeweg et al., 2010). - an interactive learning environment that allows learners to acquire conceptual knowledge on complex systems by constructing and simulating qualitative models of increasing complexity (see example of a model built with DynaLearn in Figure 1).

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Complementing conceptual mapping with conceptual modeling using the qualitative approach embedded in DynaLearn seems to advance the understanding of both static and dynamic aspects of complex phenomenon.

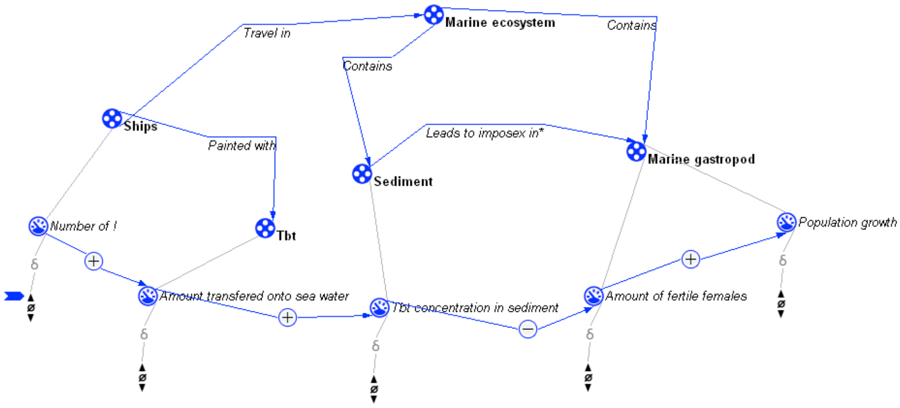

Figure 1: Sample DynaLearn model for an ecosystem

3 The study

A series of studies were conducted aiming to assess students' understanding of ecological complex systems and their gradual acquisition of system thinking skills (see http://hcs.science.uva.nl/projects/DynaLearn/). Throughout the studies, students were introduced to several ecological complex systems and were asked to represent these systems in concept maps and construct and manipulate conceptual models using DynaLearn. The specific question addressed in the study reported in this paper is:

- Does the "concept mapping to conceptual modelling" integrated approach affect students' understanding of the structural and behavioural aspects of complex systems, as reflected in their concept maps before and after the learning process?

A group of ten Junior-high-school students participated in the study. They were exposed, amongst other instructional methods, to the "Learning by Modelling" (LbM) approach using DynaLearn. In addition, the group attended a field trip, lab activities and lectures.

We compared the concepts maps produced at the beginning and the end of the learning process. While the first map represented intuitive thinking, the second map reflected the effect of the various learning tasks upon learning. Five criteria were used to assess the level of complexity understanding as represented in the concept maps:

1. The **configuration** of the concept map
   - Hierarchical type (scored 'H' followed by a number indicating hierarchical levels)
   - Net or web type (N)
2. **Focus** of the representation - either on structural aspects (S or s depending on intensity) or on processes (P or p depending on intensity).
3. The **organizing principle** used to arrange the components of the map:
   - Biological principle - relating to formal, systematic classification of living organisms (Sys)
   - Ecological principle - relating to the distribution of living organisms and non-living components in their habitat (E).
4. The type of **relationships** between the entities of the ecosystem:
   - Mostly inclusive (R1)
   - Mostly indicating a causal or process relationship (R2)
   - Both inclusive and causal relationship (R3)
5. Level of **scientific accuracy** of the representation:
   - High scientific accuracy (Ac3)
   - Medium scientific accuracy (Ac2)
   - Low scientific accuracy (Ac1)

3.1 *Sample results*

Table 1 provides data on each of the five criteria used in analysing the concept maps. A synthesis of the data from the Table indicate:

- Increase (40% → 71%) in Net-type, and decrease (60% → 29%) in hierarchical types of representations
- Increase (60% → 86%) in the use of ecological organizing principles and decrease (40% → 14%) in using formal-classification organizing principles
- No change in the type of relationships represented. Most representations are of mixed inclusive/process type of relationships (70% → 71%)
- Slight decrease in scientific accuracy (80% → 70%)

Table 1: Analyses of Concept Maps Drawn by the students

Student Id.	Structure		Focus On		Organizing Principle		Relationship *		Scientific Accuracy	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	H2	-	S	-	E	-	R3(2/4)	-	Ac3	-
2	H2	-	S	-	E	-	R1(6/0)	-	Ac3	-
3	H4	N	sp	Ps	Sys	E	R3(8/7)	R3(5/6)	Ac3	Ac3
4	N	N	P	P	E	E	R3(8/10)	R3(6/10)	Ac3	Ac3
5	H3	H2	S	Sp	Sys	E	R1(7/0)	R1(5/2)	Ac1	Ac2
6	H3	N	sp	sp	E	E	R3(7/5)	R3(4/3)	Ac3	Ac3
7	N	N	sP	Ps	E	E	R3(16/12)	R3(10/7)	Ac3	Ac3
8	N	H	sP	sp	E	E	R3(9/12)	R3(5/2)	Ac2	Ac3
9	N	N	sP	sp	Sys	Sys	R3(4/7)	R1(10/3)	Ac3	Ac2
10	H	-	sp	-	Sys	-	R1(8/3)	-	Ac3	-

* Ratio between inclusive/processes relationship

Analysis of the data obtained through the modelling unveils three main themes. The first theme concerns the way **students' perception of the mapping/modelling aim** changed from a focus on local and specific aspects – "How much effort the patella (a kind of mussel) exerts in attaching the rock in varying intensities of the waves?" – to a more systemic view of the phenomena – "The relationship between wave intensity and rock population?" The more generic descriptions in later representations imply also that the students were able to view the phenomena as particular instance of broader categories, in which multiple-variables causal relationships take place.

The second key theme relates to **students' perception of the diverse types of relationships within the system**. The patterns observed in the data collected are summarized in Table 2.

Table 2: Configurations of relationships in students' models and representations.

Type of causal relationship	*Representation*	*Example*
Single/unidirectional	A→B	*Wind affects the attachment of the patella to the rock*
Single/unidirectional/parallel/independent	A→B B→C	*Wind affects the power of the waves* *The power of the waves affects the attachment of the patella*
One-to-many	A ↗B →C ↘D	*The wind affects the power of the waves, the attachment of the patella and the number of barnacles*
Chain of relationships	A→B→C	*The wind affects the power of the waves that affects the attachment of the patella*
Feedback loop - mutual relationship	A↔B	*The more predators, the less prey; the less prey, the less predators*
Feedback loop - cyclic	A→B→C ↑_____↓	*The more intensive the scuba-diving, the more coral reef damage; the more damage, decrease in reef attractiveness; the less attractiveness, decrease in diving pressure; the less diving, recovery of the coral reef; the more recovery, increase in scuba-diving …*

Comparing the relationships included in students' early attempts with those from late stages, the following changes were observed:

- Decrease in single/unidirectional relationships (40% → 10%)
- Decrease in parallel/unidirectional relationships (20% → 10%)
- Increase in one-to-many relationships (0% → 10%)
- Increase in chain-relationships (30% → 50%)
- Increase in feedback-loop relationships (0% → 20%)

The inclusion of "chain" and "feedback" type of relationships among entities in most representations and explanations at the end of the course (70%) are clearly indicative of students' perception of the complex configuration of relationships among the system's multiple variables. In addition, it is indicative of students' perception of the dynamic aspects embedded in the system's behaviour.

The third theme focuses on the possibilities afforded by the mapping/modelling activities, as expressed by the students in their reports along the different phases. Sample expressions by the students:

- "The modelling activity enabled to understand the dynamics of the system"
- "The modelling activity allowed to study many variables and many relationships"
- "The modelling activity taught me about direct and indirect effects"
- "The modelling activity taught me that some changes have long-term and far effects – If you touch one thing, everything can change"
- "The modelling activity taught me that nature is in an equilibrium state"

Most of these expressions provide evidence that the mapping/modelling activity is viewed as a tool for exploring the dynamic aspects of systems.

4 Concluding remarks

In this paper we presented a pedagogical approach for supporting students learning about complex systems, in the form of a progression from concept mapping to conceptual modelling. Concept mapping tasks allowed immediate and intuitive construction of representations of the system under study. As well it served us as powerful analysis tool of the development of students' understandings of the structural aspects of the system, and the web of relationships and causal links in it. Modelling tasks following the concept mapping tasks, allowed students to construct runnable models of the system, to explore its dynamic aspects, and to examine predictions and hypotheses about its behaviour. We believe that this pedagogical integration is of valuable twofold contribution: for the students to construct gradually their comprehensive understanding of complex systems; and for us researchers to trace closely after students' gradual acquisition of system thinking skills and a systems worldview.

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