Learning about Ecological Systems by Constructing Qualitative Models with DynaLearn

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Abstract

A qualitative model of a system is an abstraction that captures ordinal knowledge and predicts the set of qualitatively possible behaviors of the system, given a qualitative description of its structure and initial state. This paper examines an innovative approach to science education using an interactive learning environment that supports learners in expressing and simulating conceptual knowledge by building qualitative models in ecology. The learning environment and tools are being developed as part of the Dynalearn qualitative modeling research project, funded by the European Union's 7th framework programme and carried by a consortium of eight participant universities. In summing up the results, it is clear that from the perspective of systems thinking, the modeling activity affected students' perception of systems and represent it in a more dynamic and comprehensive way.

Key Words: Qualitative modeling, Qualitative Reasoning, Science Education, Interactive environment, Complex systems

Introduction

Understanding complex systems has become a challenging intellectual endeavor for scientists and science students as well (Jacobson & Wilensky, 2006). The development of systemic approaches since the early years of the previous century, opened ways of thinking-about and studying phenomena in the world, unveiling aspects, interrelationships and processes that were overlooked by traditional science.

For science students, the systems approach and its specific concepts (e.g., emergence, self-organization, and non-linearity) represent a serious learning challenge. Portions of this knowledge appear to them epistemologically counterintuitive, and/or incongruent with the approaches, assumptions and practices characterizing the way they learn Science with the curricula prevalent in educational systems.

This paper is part of a larger study conducted with Junior High-School students aiming to assess the contribution of Qualitative Modeling (QM) with "DynaLearn" modeling environment, to students' system thinking and understanding of ecological systems.

This paper focuses on the contribution of QM with DynaLearn to students' ability:

- To understand and represent complex ecological systems;
- To construct qualitative models of systems; and
- To apply the systemic perspective in different ecological contexts and phenomena.

Theoretical Framework

Previous research detected many difficulties students face when dealing with complex systems (e.g., Assaraf & Orion, 2005; Hmelo-Silver & Pfeffer, 2004). These studies refer to students difficulties in developing a holistic perception of the system's structure and its multiple-variables configuration of relationships (Jacobson, 2001); in understanding non-linear effects resulting from fluctuations in these variables (Plate, 2010); identifying feedback loops and understanding their role in the system's behavior (Moxnes, 2000); distinguishing among the different levels of a system's behavior - e.g., specific causal relationships at the components level or emergent behaviors at the system level (Levy & Wilensky, 2008); or in predicting the system's behavior in varied scenarios - e.g., changing conditions within the system or in its environment (Hmelo-Silver & Pfeffer, 2004). The obvious conclusion from these observations is that there is a need to develop appropriate pedagogical strategies and instruments for supporting students' learning of complex systems.

In recent years, there is strong support for the idea that Learning by Modeling (LbM), namely learning by manipulating and/or constructing models of the systems under study, is a promising pedagogical approach that can support students' learning of complex systems (Bredeweg & Forbus, 2003; Hmelo-Silver, Holton & Kolodner, 2000; Levy & Wilensky, 2008).

Current development of powerful computer tools allow scientists as well as science students to engage in highly sophisticated modeling processes, to conduct virtual experiments by manipulating a wide range of variable-configurations and scenarios, and to study a system's behavior in prospective scenarios.

Different approaches are taken by researchers as to the nature of the modeling process to be addressed as "natural" to students' intuitions. One of the approaches argues for the value of qualitative modeling (QM) for learning that leans on Qualitative Process Theory (QPT) (Forbus, 1984; Forbus et al., 2001). Bredeweg et al. (2009) suggest that qualitative reasoning "*captures human interpretation of reality, and provides a conceptual account that explains why a system has certain behavior… The Qualitative Reasoning terms (in fact a symbolic logic-based vocabulary) used in the model mimic the way humans understand and explain the* [system's] *observable behavior"*. In educational implementations of QM, Qualitative Models are built by learners without the use of numerical or quantitative information. The models represent a conceptual account of the structural and behavioral features of a system under study, and of the network of causal relationships underlying its behavior.

This study is centered on the implementation of the Learning by Modeling approach using a QM environment, "DynaLearn. DynaLearn (DL) learning environment supports the construction of models in a succession of Learning Spaces – (LS1 to LS6) from simple representations (entities and relationships), toward more complex representations (quantities, quantity spaces, direct and proportional relationships, feedback loops, conditions and assumptions) as seen in Figure 1. Figure 2 and Figure 3 illustrates the simulation of the model (Figure 1): state graph and value history).

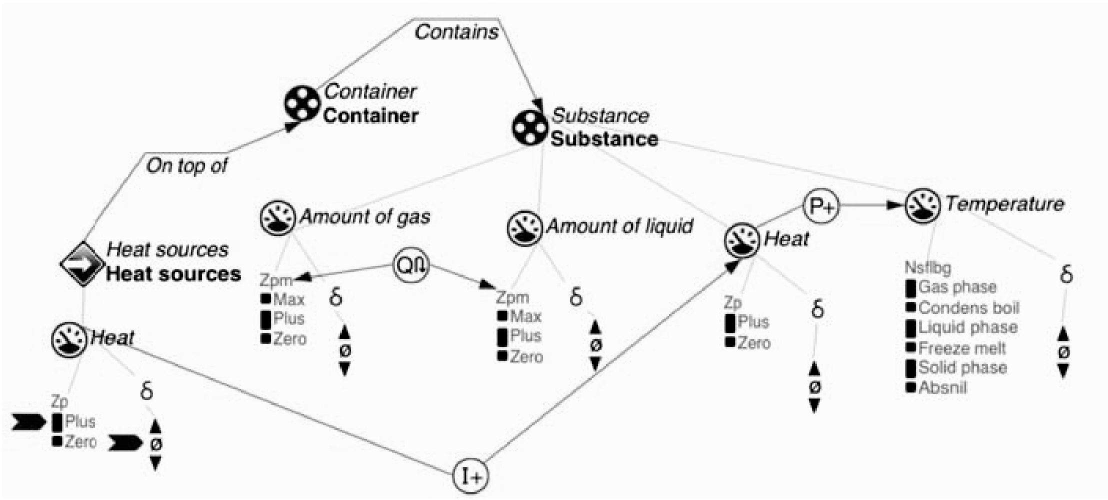

Figure 1: Learning Space (LS) 5 – Conditional knowledge (expression)

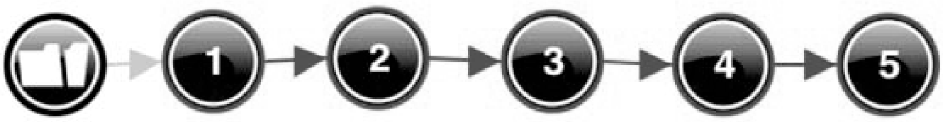

Figure 2: Learning Space (LS) 5 – Conditional knowledge (results, state-graph)

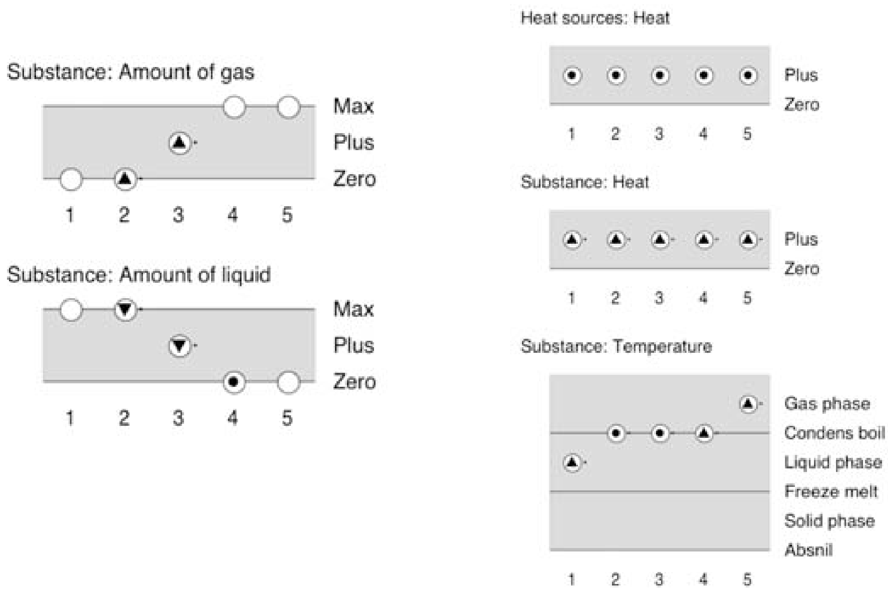

Figure 3: Learning Space (LS) 5 – Conditional knowledge (results, value history)

Method

Participants were 25 High School students in two groups, attending a summer course in Marine Biology comprising of short lectures, lab activities and a field trip. In addition as treatment variable, the experimental-group (DL) completed a set of modeling tasks using DynaLearn, while the control group (C) that did not use DynaLearn did a Web-based inquiry-task.

Data collection: The data collection was conducted using 3 instruments:

Concept mapping: The system's concept map was constructed twice by DL group (pre- and post-intervention) and once by C group.

Modeling Products: The students constructed a series of models using DynaLearn's learning spaces 2, 3 and 4. Following each modeling activity, they documented their experiences, answering questions about their models, the modeling process and the insights gained from one modeling step to the next.

Models' documentation: Follow the work of the experimental group.

Results

Question 1: On the contribution of qualitative modeling with DynaLearn to students' ability to understand and represent complex ecological systems

Students' concept maps were analyzed focusing on the following variables:

- Overall configuration of the system's representation - e.g., hierarchical or Net-type.
- Foci - focus on structural static properties or on dynamic aspects (processes and causal relationships).
- Guiding organizing principle: e.g., formal-classification principles or ecological-systems' principles.
- Type of relationships: e.g., mainly structural related to inclusive relationships, or referring to causal processes and chains.
- Scientific accuracy: on a scale from high to low level of accuracy.

A brief account on some results follows:

Pre- post- experimental group concept maps comparison:

- Increase (40% → 71%) in Net-type, and decrease (60% → 29%) in hierarchical, types of representations
- Increase (60% → 86%) in the use of ecosystemic organizing principles and decrease (40% → 14%) in using formal-classification organizing principles increase in representing structural relations (10% → 29%) and mixed structural/process relationships (60% → 71%)
- Slight decrease in scientific accuracy (80% → 70%)

Concept map comparison between experimental and control groups:

- None of the representations in the C group was Net-like
- Less ecosystemic representations in the C group (DL-86% vs. C-54%)
- Most representations in the C group were of structural type (DL-29% vs. C-62%)
- Less representations in the C group combined structural/process relationships (DL-79% vs. C-38%)
- Less scientific accuracy in C group's representations (DL-71% vs. C-23%)

Question 2: On student's ability to construct qualitative models of an ecological system

Brief summary of results for three of the variables considered:

Students' ability to define the phenomenon to be modeled:

At first, half of the students phrased their modeling aim as specific questions, e.g.,: *How much effort the patella exerts when attaching to the rock in varying intensities of waves.*

At the end of the modeling activities most students (80%), defined a phenomena in more generic and systemic ways, i.e., *the relationship between crabs, barnacles and patella; the effect of jellyfish on the Israeli marine shore.*

Understanding types of relationships in the system:

Values for this variable include the relationships: single/unidirectional; parallel /unidirectional; one-to-many; causal-chains; feedback-loops. Along the modeling activities we 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%)

Insights related to complexity and the worth of modeling for learning:

Qualitative analyses of student's documentation unveil their perception of complexity and the contribution of modeling for understanding it. Examples of insights: "The modeling activity enabled predictions"; "The modeling activity enabled to understand the dynamics of the system"; "The modeling activity allowed studying many variables and many relationships"; "The modeling activity taught me that some changes have long-term and far effects – If you touch one thing, everything can change".

Question 3: On the contribution of QM to student's ability to understand different phenomena and systems

"Challenging questions" were administered to both groups after the intervention. Students had to apply the knowledge gained to provide descriptions, explanations, and predictions concerning a marine ecosystem. Sample results:

- The average total score by DL students was much higher than that of the C group (78.3% vs. 45.8%).
- DL students outperformed C students (DL-59% vs. C-36%) in understanding different types of relationships in ecosystems.
- On predicting changes that might occur in a system in response to an interference (external agent, change in conditions), most students in the DL group (60%) succeeded in delineating long chains of events, vs. none in the C group.

Conclusions

Overall, the students acquired rapid mastery of the skills and procedures required for constructing models with DynaLearn. As the modeling sessions advanced, their products reached high levels of complexity. At the end of the course, an increase in experimental group students' ability to represent a system's structural, functional and behavioral features was observed. This observation was obtained in relation to the group's initial performance, and in comparison with the control group's performance.

At the end of the course, an increase in students' perceptions and representations of multiple-variables causal relationships, causal chains and feedback loops was observed. This is indicative of students' evolving understanding of the complexity of a system and of the type of causal configurations provoking its behavior.

Student comments (qualitative account of the group's work) reinforced the conclusions from the data. On this, a representative comment by a student asserted: "*The modeling activity taught me* *that some changes have long-term and far effects – If you touch one thing, everything can change*"

Knowledge and systemic approach gained during the course supported students' capability to apply these for addressing challenging questions about a system in a new context. The experimental group clearly outperformed the control group in this task.

Acknowledgement

The work presented in this paper is co-funded by the EC within the 7th FP, Project no. 231526, and Website: http://www.DynaLearn.eu.

References

Assaraf, O. & Orion, N. (2005). Development of system thinking skills in the context of Earth system education. *Journal of Research in Science Teaching, 42*, 518-560.

Bredeweg, B. & Forbus, K. (2003). Qualitative Modeling in Education, *AI Magazine, 24*(4).

Bredeweg, B., Gómez-Pérez, A., André, E. & Salles, P. (2009). DynaLearn – Engaging and Informed Tools for Learning Conceptual System Knowledge. *Cognitive and Metacognitive Educational Systems (MCES2009).* Pirone. R., Azevedo, R. and Biswas, G. (eds.), pages 46-51, AAAI Fall Symposium, Arlington, Virginia USA, 5-7 November, Technical report FS-09-02, AAAI Press.

Forbus, K. D. (1984). Qualitative Process Theory, *Artificial Intelligence, 24*(1-3), 85-168.

Forbus, K. D., Carney, K., Harris, R., & Sherin, B. L. (2001). A Qualitative Modeling Environment for Middle-School Students: A Progress Report. *Paper presented at the Fifteenth International Workshop on Qualitative Reasoning*, 17-19 May, San Antonio, Texas.

Hmelo, C. E., Holton, D. L., & Kolodner, J. L. (2000). Designing to learn about complex systems. *The Journal of the Learning Sciences, 9*, 247-298.

Hmelo-Silver, C. E., & Pfeffer, M. G. (2004). Comparing expert and novice understanding of a complex system from the perspective of structures, behaviors, and functions, *Cognitive Science, 1*, 127-138.

Jacobson, M. J. (2001). Problem solving, cognition, and complex systems: Differences between experts and novices. *Complexity, 6*(3), 41-49.

Jacobson, M. J., & Wilensky, U. (2006). Complex systems in education: Scientific and educational importance and implications for the learning sciences. *The Journal of the Learning Sciences, 15*(1), 11-34.

Levy, S.T., & Wilensky, U. (2008). Inventing a "mid-level" to make ends meet: Reasoning through the levels of complexity. *Cognition and Instruction 26*, 1-47.

Moxnes, E. (2000). Not only the tragedy of the commons: misperceptions of feedback and policies for sustainable development, *System Dynamics Review 16*(4), 325-348.

Plate, R. (2010). Assessing individuals' understanding of nonlinear causal structures in complex systems, System *Dynamics Review 26*(1), 19-33.