Using ecology to enhance everyday reasoning: the case of interdependent and reciprocal causality

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ABSTRACT

This paper reports on a case study performed in the 3rd cycle of a developmental research that concerns the design of a CSCL environment of ecology for university students. Our focus here is set on using this environment to help students develop 'interdependent reciprocal thinking' about everyday cause-and-effect relationships. To do this, we drew upon the function of feedback loops (a) in ecosystems, (b) in everyday life, and (c) per se, respectively through NetLogo-models, familiar examples, and experiential activity. Analyzing the 44 participants' pre/post responses showed that a better understanding of how causality works in everyday contexts was finally reached.

KEYWORDS

Laundry list thinking, circular thinking, feedback loops, everyday reasoning

RÉSUMÉ

Cet article rend compte d'une étude de cas exploratoire réalisée dans le troisième cycle d'une recherche en développement qui vise la création d'un CSCL environnement d'apprentissage d'écologie. Ici, nous concentrons à son utilisation pour aider des étudiants d'université à développer de réflexion réciproque/ interdépendante concernant des relations de cause-à-effet en vie quotidienne. Pour cela, nous avons utilisé des boucles de rétroaction (a) en écosystèmes, (b) en

vie quotidienne, et (c) per se, par des modèles-NetLogo, des exemples familiers, et d'activité expérientielle, respectivement. L'analyse des 44 pré/post réponses a montré qu'une meilleure compréhensiondecausalitéen vie quotidienne a été atteinte.

Mots-Clés

Raisonnement du type 'laundry list', raisonnement circulaire, boucles de rétroaction, raisonnement à propos de la vie quotidienne

Introduction

While the world is growing more complex and interconnected, school education essentially continues to enhance the notion that knowledge is consisted of several unrelated parts. It has been argued that it does not provide students with enough opportunities to recognize existing patterns and links within and across subjects and disciplines; this way it fails in supporting students to realize the interconnectedness which underlies both natural and social worlds (Sweeney & Sterman, 2007). The resulting fragmentation of knowledge may contribute to the development and persistence of the so-called 'laundry list thinking' in the contexts of school science and everyday life.

According to Richmond (2004), the term 'laundry list thinking' refers to a rather widespread, although problematic, kind of reasoning, which can also be described by the term 'critical success factors thinking'. In order to have an idea about the basic assumptions that underlie this reasoning device, one might think of a list of factors that presumably lead to professional success, for instance. Habits like being self-confident, giving priority to the most important tasks, working with a team spirit, being consistent with deadlines and so forth, may be included in such a list. But the important thing is that the 'list' idea itself seems to imply that (a) each of the listed habits may influence professional success independently from the others, and (b) professional success cannot actually influence back all or at least some of these habits as well. Thus, 'laundry list thinking' refers to a kind of reasoning which assumes that (a) 'causal variables' operate independently on the 'effect variable', and (b) causality runs exclusively in one-direction, linear ways. In other words, it assumes that there is a list of well-defined 'causal variables' that operate on a single, well-defined 'effect variable' (a) without being connected to each other, and (b) without being influenced in turn by the 'effect variable' itself.

As it fails to highlight the web of relationships that usually characterize complex systems in nature and society, 'laundry list thinking' seems to be an obstacle for understanding how these systems work and so it needs to be replaced. More specifically, it has been argued that a shift to 'interdependent reciprocal thinking' could contribute to this direction (Mella, 2012). The assumptions that underlie this more advanced kind of reasoning are obviously different than those of the 'laundry list thinking'. In fact, they are quite the

opposite: (a) 'causal variables' operate on the 'effect variable' through an interconnected set of interdependent relationships, and (b) the 'effect variable' operates back on 'causal variables' through feedback loops. In other words, 'interdependent reciprocal thinking' assumes that 'causal variables' compose a tightly intertwined network, where both themselves and the 'effect variable' can influence each other (Richmond, 2004). This is definitely the case when reasoning about ecosystems through the currently valid idea of the 'resilient nature' (Gunderson & Holling, 2002; Scheffer, 2009).

According to the latter, the relationships among parts of an ecosystem give rise to emergent features and behaviors of it as a complex whole (Green, Klomp, Rimmington & Sadedin 2006; Mitchell, 2009; Schmitz, 2010) that may actually exist in more than one 'alternative stable states' (Scheffer, 2009). These 'stable states' are self-organized through the function of specific feedback loops. Ecosystems may shift rather abruptly from one 'stable state' to another (e.g. from 'stable state A' to 'stable state B'), when specific tipping points are reached due to feedback loops' changes that derive from intertwined interactions between critical abiotic and/or biotic factors (Scheffer, 2009). Nevertheless, performing a reverse shift (e.g. a shift from 'stable state B' back to 'stable state A') is not always possible (Scheffer, 2009): re-setting critical factors at their initial levels in order to fix the target feedback loops that, when broken, led the ecosystem to a new 'state', may actually trigger the initiation of unexpected loops between different factors and this may hinder the ecosystem's reverse transition to its previous 'state'. The above indicate rather clearly the need to be able to realize that there is a rich, complex web of relationships functioning within natural systems. In summary, nature is not considered to be constant and balancing any more, but constantly changing in both time and space in non-linear, contingent ways (Holling, 1973; Gunderson, Allen & Holling, 2010).

Since we decided to design a learning environment for supporting university students in building a meaningful, up-to-date understanding of how ecosystems work, we thought it would be worth trying to use this environment for helping them incorporate the ideas of interdependent and reciprocal causality in their everyday reasoning as well. In fact, this paper is concerned with how feasible building 'interdependent reciprocal thinking' in an everyday context may be for university students who engage with a learning environment which aims at highlighting the contingent behavior of ecosystems. Thus, our research question is the following: 'How do students reason about everyday life causality before and after their participation to a learning environment of up-to-date ecology?'.

METHODS

The overview of the study
This paper reports on a case study performed in the 3rd cycle of a developmental

research that concerns the design of a computer-supported collaborative learning environment of ecology informed by the problem-posing approach (Klaassen, 1995) in the broader context of social constructivism (Driver, Asoko, Leach, Scott & Mortimer, 1994). Our aim was (a) to design a learning environment that would highlight the contingent behaviour of ecosystems through the idea of the 'resilient nature', and (b) to be able to use this environment for helping students of educational sciences to advance their reasoning about *everyday* cause-and-effect relationships as well. In 1st paper we focus on the latter and we are particularly concerned with whether students appear ready to perform 'interdependent reciprocal thinking' about everyday phenomena after their participation in the 3rd version of our learning environment. We also designed a pre/post-questionnaire with open-ended items, followed by short interviews when needed, to collect data about the effectiveness of our learning environment. We finally analyzed students' responses using the qualitative analysis software NVivo (Gibbs, 2005) and tested for the statistical significance of their progress using the quantitative analysis software SPSS.

The participants of the study

The participants of the case study were 44, first-year educational-sciences' students at the University of Patras (age 18-19 years), who (a) had basic school-knowledge of ecology, (b) were familiar with computers and group-work, and (c) seemed to be interested in ecology in terms of raising/answering questions in the course's regular classes. They were attending an optional course of ecology offered by the co-author and volunteered to take part after being informed about the study and reassured that they could drop out at any time.

The learning environment

Students were introduced to the 'resilient nature'-idea, which favors contingency over purpose by assuming that ecosystems are characterized by (a) multiple alternative states, (b) self-organization through feedbacks, and (c) abrupt, not necessarily reversible-shifts between states (Holling, 1973; Gunderson et al., 2010). Students' introduction to these assumptions took place in five, 2-hour sessions within their course.
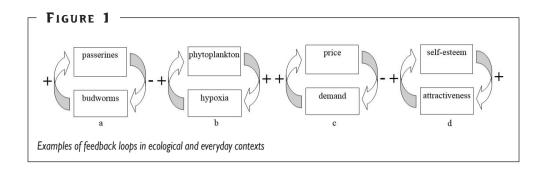
In sessions 1-4, students collaboratively worked with the four, two-version models we developed in 'NetLogo' (Wilensky, 1999) by drawing upon current ecological research about terrestrial/aquatic ecosystems facing internally/externally triggered changes. More specifically, each of our four models had two different versions that showed two different trajectories of an ecosystem, depending on initial conditions or certain human actions in the recovery plan and were based on findings of current ecological research (Table 1). So, in sessions 1-4, half of the triads explored the 1st version of the model in question and the other half the 2nd, all with the help of worksheets that

required predictions about the ecosystem's behaviour before using the model and explanations afterwards. Depending on their model-version, triads had the chance to realize that the ecosystems may either maintain their state or shift to an alternative one; and that ecosystems that already performed a shift to an alternative state may either recover their initial state or not. The whole class discussions at the end of sessions 1-4 gave students the opportunity to exchange this knowledge in order to realize that contingency is an inherent feature of ecosystems.

TABLE 1

NetLogo' Models & learning objectives per session

Sessions (S)	'NetLogo' Models (NM)	Reference Model	Learning Objectives (LO)	
S1	NM1 - Forest: forest maturation • two trajectories (initial conditions)	Gunderson et al., 2010	LO1-2	LO$_{-contingency}$
S2	NM2 - Lake: inflow of nutrients & subsequent termination of it • two trajectories (initial conditions)	Scheffer, 2009	LO1-4	LO$_{-contingency}$
S3	NM3 - Lake: inflow of nutrients & subsequent removal of nutrients & additional corrective actions • two trajectories (recovery plan)	Scheffer, 2009	LO1-4	LO$_{-contingency}$
S4	NM4 - Meadow: removal of spiders & subsequent re-introduction of spiders • two trajectories (initial conditions)	Schmitz, 2010	LO1-4	LO$_{-contingency}$

Regarding in particular the feedback loops that organize each alternative state (Figure 1: a-b), the worksheets supported students in exploring their two types and connect them to 'temporary balance' or 'state shifts'. Moreover, in the whole class discussions the students had the opportunity to discuss and contrast the function of the feedback loops in the two different trajectories of the ecosystems simulated by the two versions of each model. In the whole class discussions of sessions 1-2 in particular, we introduced the idea that feedback loops play a role in everyday life as well. Students discussed about (a) the counteracting loops functioning between factors such as the price and the demand for a product or the weight and the effort to exercise, and (b) the reinforcing loops functioning between factors such as self-esteem and attractiveness or anger and arguing with parents (Figure 1: c-d).

Finally, in session 5, we used hands-on activities to summarize and consolidate the previous work. Regarding feedback loops in particular, students performed a pair-activity, simulating the feedback loops' function with their hands' movement.

Figure 1

Examples of feedback loops in ecological and everyday contexts

Providing students with the opportunity to explore the function of feedback loops (a) in the context of ecosystems (sessions 1-4), (b) in the context of everyday life (sessions 1-2), and (c) *per se* or out of context (session 5), we aimed at promoting a non-ecological, 'complementary' learning objective: 'Causality in everyday contexts is interdependent and reciprocal or two-way, rather than independent and one-way'.

The pre/post questionnaire

A pre/post-test questionnaire with equivalent, non-identical items was administered to the students in order to give us the chance to compare students' pre/post-responses and at the same time avoid any 'noise' that might derive from students' familiarization with the items. The 1st part of each questionnaire included four, open-ended items testing students' reasoning about the behaviour of protected/disturbed ecosystems. The 2nd part included one open-ended item (item 5) testing students' reasoning about everyday cause-and-effect relationships and thus concerns us here. This required students to describe the relations among three factors of the school environment in the pre-test ('students' good performance at school', 'good teachers', and 'students' strong motives to study') and three factors of the workplace in the post-test ('employees' good performance at work', 'good employers', and 'employees' strong motives to work'); the requirement was to provide a schematic representation and explain it verbally (see Appendix). So, item 5 intended to test how students reasoned about everyday life causality before and after working within our ecological learning environment that stressed the transferability of the ideas of interconnectedness and feedback loops in social systems as well. More specifically, item 5 intended to test whether 'interdependent reciprocal thinking' that recognizes a number of reciprocal links between the factors in question, would be more frequent in students' *post*-responses than 'laundry list thinking' that doesn't. The 1st author read all the responses as soon as the students had completed the questionnaire and carried out short interviews with those whose responses needed clarification.

The analytic procedure

Using the qualitative data analysis software 'NVivo', we categorized students' responses in seven categories (Table 2) by considering *both* the type (reciprocal vs one-way) *and* the number (1-3) of the provided links in each of them. For instance, responses with three one-way links between the factors in question were coded at the '3 one-way links' category (e.g. *'the strong motives of the employees to work can lead to a good performance at work, the good performance at work can lead to a good employer, a good employer can lead to strong motives of the employees to work'* (Figure 2a). Similarly, responses with three reciprocal links between the factors in question were coded at the '3 reciprocal links' category *(e.g. 'the strongest the motives of the employees to work, the better their performance at work and vice versa; the better the employer, the better the employees' performance at work and vice versa; the strongest the motives of the employees to work, the better their employer and vice versa')* (Figure 2b). Finally, responses with a combination of the two link-types were coded for instance at the '1 reciprocal link & 2 one-way links' category: *'a good performance at work is based on a good employer and strong motives of the employees to work; an employer is better when the performance of the employees at work is better, but he is not influenced by their strong motives to work; a good employer could lead to strong motives of the employees to work but the motives are not influenced by the employees' performance at work'* (Figure 2c).

Besides counting the frequency of each category in the pre- and post-test, we also developed a scoring grid for the categories of our coding scheme (Table 2), in order to be able to statistically test students' progress. As shown in Table 2, each response category was scored twice: once regarding the *type* of the links between the examined factors and once regarding their *number*. Thus, each category got two different sub-scores that finally gave rise to its total score, as follows:

- Link-type sub-score
  The categories with 'reciprocal' links or 'reciprocal and one-way' links got the highest link-type sub-score (1).
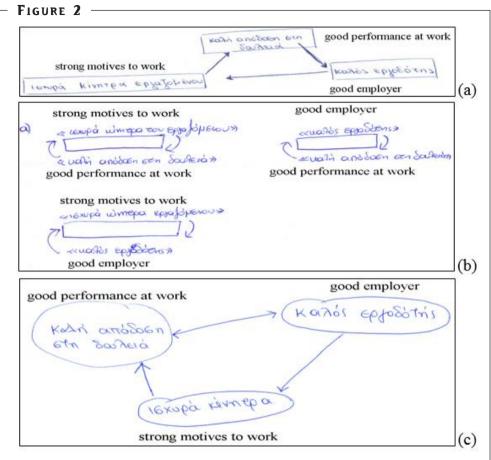 The categories without any 'reciprocal' links got the lowest link-type sub-score (0).
- Link-number sub-score
  The categories with three links (i.e. all the three factors were connected to each other) got the highest link-number sub-score (3).
  The categories with only one link (i.e. only two of the factors were connected to each other) got the lowest link-number sub-score (1).
- Total score
  The sum of the sub-scores for each category gave rise to its total score (range 2-4).

For instance, the response '*the strong motives of the employees to work can lead to a good performance at work, the good performance at work can lead to a good employer, a good*

Figure 2

Responses coded at the '3 one-way links' category (a), '3 reciprocal links' category (b), and '1 reciprocal link & 2 one-way links' category (c)

Table 2

The scoring grid

Categories of students' responses	Link-type sub-score	Link-number sub-score	Total score
'3 reciprocal links'	1	3	4
'2 reciprocal links'	1	2	3
'1 reciprocal link'	1	1	2
'1 reciprocal link & 2 one-way links'	1	3	4
'1 reciprocal link & 1 one-way link'	1	2	3
'3 one-way links'	0	3	3
'2 one-way links'	0	2	2

employer can lead to strong motives of the employees to work' which was coded at the '3 one-way links' category, gained (a) a sub-score of 0 for its link-type, (b) a sub-score of 3 for its link-number, and (c) a total score of 3 as a whole.

Finally, a Wilcoxon signed-rank test was performed to determine whether the three scores assigned to the categories of students' responses differ in a statistically significant way between the pre-test and the post-test. So, the findings that follow have to do with (a) the frequencies of our categories in pre/post-test, and (b) the statistical significance of their difference.
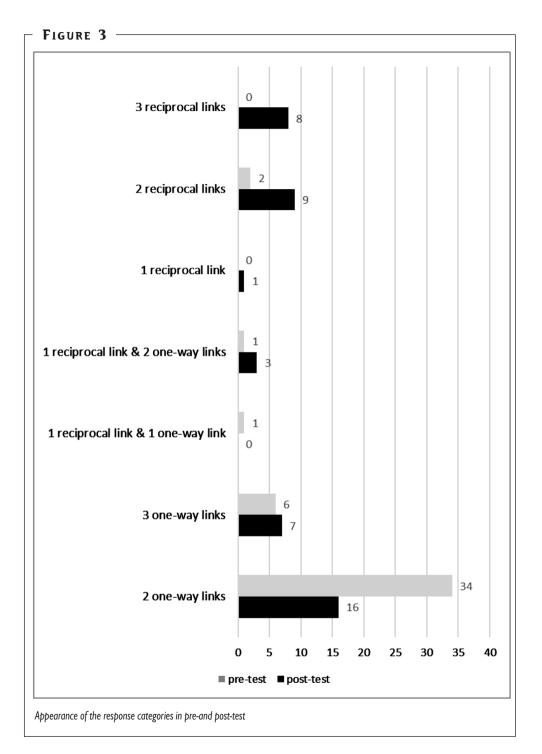
FINDINGS

According to our findings, all but one of the desired response categories (i.e. those with reciprocal links) appear more frequently in the post-test than they do in the pre-test. More specifically, as shown in Figure 3, the '3 reciprocal links'-category which is absent from the pre-test, appears 8 times in the post-test; in other words, the post-responses of 8/44 students are coded in this category. Similarly, the post-responses of 9/44 students are coded in the '2 reciprocal links'- category and the post-response of 1/44 is coded in the '1 reciprocal link'-category; in the pre-test, only 2/44 and 0/44 students contribute respectively to these categories. Finally, the '1 reciprocal link & 2 one-way links'-category, which initially appears only once, gathers the post-responses of 3/44 students. So, the only response category that includes reciprocal links and does not increase its frequency in the post-test is the '1 reciprocal & 1 one-way link'-category; this is absent from the post-test while it appears once in the pre-test.

Moving to the response categories that lack reciprocal links, we note that the '3 one-way links'-category appears almost equally in the pre- and post-test: 6/44 and 7/44 students contribute to it respectively. On the contrary, the '2 one-way links'-category, which is dominant in the pre-test, appears much less frequently in the post-test: 34/44 students contribute to this category in the pre-test, while only 16/44 students do so in the post-test.

Finally, a Wilcoxon signed-rank test for both the sub-scores of the categories *did* show statistically significant differences between the pre- and post-test (link-type sub-scores $_{pre-post}$: Z = -4.123, p < 0.01; link-number sub-scores $_{pre-post}$: Z = -3.000, p < 0.01). The same was valid for the categories' total scores, as well (total scores $_{pre-post}$: Z = -4396, p <0.01).

DISCUSSION

Based on the findings we presented above, we may suggest that the idea to use a learning environment about up-to-date ecology for helping students incorporate the notions of interdependent and reciprocal causality in their everyday reasoning appears

Figure 3

Appearance of the response categories in pre-and post-test

to be feasible: our non-ecological, 'complementary' learning objective concerning a better understanding of how causality may work in everyday contexts seems to be adequately met. After their engagement with the learning environment, some students (8/44) connect all three factors that concern the workplace with reciprocal links; this indicates the highest level of understanding of interdependence and reciprocality concerning everyday causality that could actually be indicated in the context of item 5.

Regarding the idea of reciprocality in particular, it is worth noticing that there is a significant increase in the use of reciprocal links after students' engagement with the learning environment. The number of those who use at least one reciprocal link in their responses increases from 4/44 in the pre-test to 21/44 in the post-test. So, it seems that our presentation of the feedback loops in the ecological context, the everyday context and *per se,* had a positive impact on highlighting the reciprocal nature of everyday cause-and-effect relationships.

Shifting our focus on the idea of interdependence this time, we note a significant increase in the use of three links. The number of students who use three links in their responses increases from 7/44 in the pre-test to 18/44 in the post-test. We also note a decrease in the use of two links. The number of those who use two links in their responses decreases from 37/44 in the pre-test to 25/44 in the post-test. Moreover, it is worth noticing that there is a difference in the link-quality; in the post-test, the students who respond with 'two *reciprocal* links' are more (2/44 vs 9/44) while those who respond with '2 *one-way* links' are fewer (34/44 vs 16/44). This indicates a significant retreat of students' tendency to consider one of the three factors as the 'effect' and the other two factors as independent 'causes' exclusively. It seems then, that the presentation of the feedback loops in different contexts and *per se,* had a positive impact on highlighting the interdependent nature of everyday cause-and-effect relationships as well.

The development of interdependent reciprocal reasoning strands about ecological or everyday phenomena has actually to do with systems thinking (Richmond, 2004). Although our intention was clearly not to design a learning environment focused on systems thinking like other researchers have done (Assaraf & Orion, 2005; Boersma, Waarlo & Klaassen, 2011) it would be very interesting to move towards this direction in the future. Combining equally (a) conceptual learning objectives that have to do with challenging biological concepts, and (b) systems thinking learning objectives that have to do with *both* biological *and* social systems seems challenging and meaningful enough to pursuit.

ACKNOWLEDGEMENTS

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Appendix

Item 5

Pre-test: What do you think may be the relation of 'students' good performance at school', 'good teachers', and 'students' strong motives to study'? Please reply by (a) drawing a sketch, and (b) explaining your sketch in words.

Post-test: What do you think may be the relation of 'employees' good performance at work', 'good employers', and 'employees' strong motives to work'? Please reply by (a) drawing a sketch, and (b) explaining your sketch in words.