TOWARDS A LEARNING ENVIRONMENT FOR CHALLENGING THE IDEA OF THE BALANCED NATURE: INSIGHTS FROM THE FIRST CYCLE OF RESEARCH

Georgios Ampatzidis and Marida Ergazaki
University of Patras, Greece

Abstract: This paper reports on insights from the first cycle of a developmental research study aiming at the design of a learning environment that could effectively support non biology-major students (a) in challenging the widespread view of the ‘balanced nature’ and constructing a meaningful, up-to-date understanding about how ecosystems may function, and (b) in enhancing context-free ideas like interdependent and circular causality that underlie systems thinking. Our focus here is set on whether and how students’ reasoning about ecosystems’ response to human-driven disturbance or protection has been altered after their engagement with the first version of our learning environment, as well as on how the conceptual aspect of the latter could be further elaborated. Considering social constructivism and problem-posing approach, we developed a computer-supported, collaborative learning environment for highlighting ecosystems’ contingent behaviour through the currently valid idea of the ‘resilient nature’. Forty-one, 1st-year students of educational sciences were actively introduced to the basic assumptions of the idea of the ‘resilient nature’ in four, 2-hour sessions within an optional course of ecology, by exploring our *‘NetLogo’* models of protected or disturbed ecosystems with the aid of worksheets. The analysis of students’ responses to certain items of the pre/post-questionnaire shows that the idea of the contingent behaviour of ecosystems was reached only by a few students, while most of them shifted from the idea of the always-recovering nature to the idea of the never-recovering one. Implications about elements of the learning environment that need to be reconsidered and elaborated are thoroughly discussed.

Keywords: ecological reasoning; model-based learning; collaborative learning; teaching about ecosystems; teaching about resilient nature.

INTRODUCTION

Research on the ways students of different age reason about natural systems has revealed a widespread belief in the ‘balance of nature’ (Zimmerman & Cuddington, 2007). This ‘balance’ is supposed to be an inherent, self-preserved feature of ecosystems (Cuddington, 2001) and lies at the core of students’ reasoning about the response of the latter to human-driven disturbance or protection (Ergazaki & Ampatzidis, 2012).

Referring to the rather out-dated cybernetic view, the idea of the 'balanced nature' appears to hinder environmental awareness and conceptual understanding. In fact, it may undermine the significance of not disturbing ecosystems through the assumption of their almost 'magic' power to recover initial state (Westra, 2008). Moreover, it opposes the current idea of the 'resilient nature' that favours contingency over purpose by assuming multiple alternative states, self-organization through feedbacks, and abrupt-not necessarily reversible-shifts between states (Holling, 1973; Gunderson & Holling, 2001; Scheffer, 2009). Apart from providing students with a better explanation about nature, this idea could also give them an appropriate context for fostering systems thinking skills, considered as crucial for all aspects of life (Boersma et al., 2011).

Thus, our study addresses the question of whether it is feasible to design a learning environment that could effectively support non biology-major students (a) in challenging the idea of the 'balanced nature' and constructing a meaningful, up-to-date understanding about how ecosystems may function, and (b) in using this understanding to enhance context-free ideas like interdependent and circular causality that underlie systems thinking.

In this paper we are particularly concerned with identifying (a) whether and how students' reasoning about the ways ecosystems may respond to human-driven disturbance or protection has been altered after their engagement with the first version of our learning environment, and (b) those points of the latter that need to be reconsidered. So, the questions here are:

(a) 'How do students reason about ecosystems' behaviour before and after their participation in the learning environment?'. More specifically: 'What kind of predictions do they make about the future of disturbed or protected ecosystems and how do they justify them?'; 'Do they really predict a contingent behaviour by appealing to alternative states, feedbacks and reversible/irreversible shifts or not?'

(b) 'What needs to be elaborated in the first version of the learning environment in order to enhance its effectiveness?'.

METHODS

The overview of the study

In this study of developmental research (Akker et al., 2006), we drew upon social constructivism (Vygotksy, 1978) and problem-posing approach (Klaasen, 1995) to design a computer-supported, collaborative learning environment, which aims at supporting non-biology major students in understanding the contingent behaviour of ecosystems through the basic assumptions of the idea of the 'resilient nature'. We also developed a pre/post questionnaire with open-ended items in order to collect data about the effectiveness of our learning environment and we analyzed students' responses using 'NVivo'.

The participants

The first cycle of the research we report here was carried out with forty-one, first-year students of educational sciences at the University of Patras. All of them were enrolled for an optional course of ecology offered by the second author and volunteered to take part in the study after they had been informed about it. The participants (a) had basic ecological knowledge due to a university-entrance course, (b) were familiar with computers and group-work and (c) were rather active in terms of raising / answering questions in the course's regular classes.

The learning environment

The learning environment aims at highlighting the contingent behaviour of ecosystems through the basic assumptions of the idea of the 'resilient nature'. In other words, the learning objectives (in short, 'LO') have to do with understanding these assumptions ('LO1'-'LO5') and with using them in order to challenge the notion of balance as an inherent feature of nature and finally move to the notion of contingency ($LO_{-contingency}$). More specifically:

- 'LO1': In the absence of disturbance, an ecosystem may have multiple alternative states (see 'multiple *natural* states').
- 'LO2': Each state is self-organized through feedbacks.
- 'LO3': Shifts from one state to another may occur abruptly at specific tipping points where feedbacks change.
- 'LO4': Shifts between alternative states may be irreversible.
- 'LO5': Shifts between alternative states may be reversible but in that case the system shows hysteresis.
- '$LO_{-contingency}$': The natural systems show a contingent and not pre-determined behavior ('resilient nature' vs 'balanced nature').

Students were actively introduced to the target assumptions in four, 2-hour sessions within the ecology course they were attending. In each session, they collaborated in triads to explore a model within '*NetLogo'* (Wilensky, 1999), with the aid of a worksheet that required predictions about the ecosystem's behaviour before using the model and explanations afterwards. The four '*NetLogo'* models we developed (in short, 'NM') to pursuit the learning objectives, simulated terrestrial or aquatic ecosystems faced with internally or externally triggered changes, and were based on findings of current ecological research. More specifically:

- 1st session - 'NM1-Forest': the model simulated the maturation of a tree species in a forest (Gunderson et al., 2010), which was inhabited by two tree species (spruces, aspens) and four animal species (bugs, budworms, moose and passerines). The focus here was on 'LO1', 'LO2' and '$LO_{-contingency}$'.
- 2nd session - 'NM2-Lake': the model simulated an inflow of nutrients in a lake (Scheffer, 2009), which was inhabited by phytoplankton, zooplankton, one species

of sea plants and two species of fish. The focus here was on 'LO1'-'LO4' and 'LO$_{\text{-contingency}}$'.

- 3rd session - 'NM3-Lake': the model simulated an inflow of nutrients in a lake, the subsequent removal of nutrients and other corrective actions that took place in order to restore the lake (Scheffer, 2009). The lake was inhabited by two species of plants and two species of fish. The focus here was on 'LO1'-'LO3', 'LO5' and 'LO$_{\text{-contingency}}$'.
- 4th session - 'NM4-Meadow': the model (see appendix) simulated the removal and subsequent re-introduction of an animal species (spiders) from a meadow (Schmitz, 2010). The meadow was inhabited by two species of plants and three species of animals (grasshoppers, spiders and bugs). The focus here was on 'LO1'-'LO4' and 'LO$_{\text{-contingency}}$'. Students were also engaged in reasoning about ecosystems' behaviour through 'landscape models' made of plasticine and cardboard.

The pre/post questionnaire

Students were administered a pre/post questionnaire, the first part of which included five, open-ended items about the behaviour of protected or disturbed ecosystems. The pre/post items were equivalent and all of them - except the second one - aimed at probing specific target assumptions as *justifications for the contingency* ($_{\text{J-contingency}}$) of ecosystems' behavior (see 'LO1-5'$_{\text{J-contingency}}$). More specifically:

- Item 1 - 'protected ecosystem': students were asked to reason about the future of a terrestrial / aquatic national park under human protection. The focus here was on 'LO1'$_{\text{J-contingency.}}$
- Item 2 - 'feedbacks': students were asked to explain the population size control in a lake / swamp through feedback-mediated self-organization and the loss of control through feedback-change at a tipping point. The focus here was on 'LO2' and 'LO3'.
- Item 3 - 'disturbed ecosystem: biotic change': students were asked to reason about the future of a lake / forest where a new population was first added and then removed by humans. The focus here was on 'LO4-5'$_{\text{J-contingency}}$.
- Item 4 - 'disturbed ecosystem: abiotic change': students were asked to reason about the future of a lake where the nutrients / salinity of the water was increased and subsequently decreased due to human actions. The focus here was on 'LO4-5'$_{\text{J-contingency}}$.
- Item 5 - 'schemes': students were asked to choose among schemes representing ecosystems that were faced with a disturbance (Gunderson et al., 2010) and explain their choice. The focus here was on 'LO1-5$_{\text{J-contingency}}$.

The questionnaire was first administered to non-participating students with a 'think aloud' protocol and elaborated accordingly. Here we are only concerned with items 1 and 4.

The analytic procedure

Students' responses to the pre/post questionnaires were transcribed and coded within the environment of the qualitative data analysis software 'NVivo'. The several 'categories' that emerged were organized into a 'coding scheme' divided (a) in students 'predictions' (e.g. *'Full recovery', 'Partial recovery', 'Contingent behaviour'*) about the future of the ecosystem in question, and (b) in students' 'justifications' for what they predicted (e.g. *'Recovery mechanisms', 'Incomplete recovery process', 'Possibility of long-lasting effects').* The coding was performed by both the authors with a satisfactory agreement: Cohen's Kappa with regard to items 1 and 4 that concern us here was estimated to 0.85.

FINDINGS

Regarding students' reasoning about the future of a protected ecosystem like a terrestrial or an aquatic national park (item 1), we note that in the post-test students found even *more* appealing the idea that the protected ecosystems remain unchanged, which was not a desirable outcome. More specifically, the prediction of the 'same picture' became *more* frequent in the post-test, while the idea of 'self-regulation through populations' relationships' appeared to be replaced by the more advanced idea of 'self-regulation through counter-acting loops' in students' warrants (Figure 1). In their own words:

- *"Since the forest is protected from fires and other disturbances, the population of plants will not change, thus the population of animals will also not change, because the food chain will remain the same."* (pre-test)
- *"After some years, it is reasonable to believe that some of the populations like the sea plants would grow in number and others would decrease and this way there would be changes in the food chain of the aquatic park. Because of the balancing loops existing in the water, the situation will eventually change back and everything will be normal again."* (post-test)

On the contrary, the predictions of a 'different' or 'possibly different' picture, due to 'changes (or 'possible changes') in population size', became *less* frequent in the post-test (Figure 1). In students' own words:

- *"There is a chance that some plant population will decrease in future, because they will be consumed by animals. Possibly, some animal populations will decrease too, because they won't be able to find their prey or they will die by natural causes."* (pre-test)
- *"After some years, the animal and plant populations living in this aquatic park will change. The populations of sea plants and phytoplankton will raise and so will the animals that live on them (sea turtles for example). Some fish populations will decrease though, and so will the animals that live on them (bigger fish and sea birds, for example)."* (post-test)

Nevertheless, the idea of ‘multiple natural states’ for a protected ecosystem *did* actually serve as a warrant for the ecosystem’s contingent behaviour by some students (Figure 1). In their own words:

- *“Since no external factor affects it, the sea park will rather remain stable. Nevertheless, it is possible for an ecosystem to alter (for instance the populations may change) because of internal factors, even when there are no external factors affecting it. An ecosystem may be in more than one natural states and the shift among these states may be triggered by internal factors, even when no external disturbance (human or natural activity) exists.”* (post-test)

Moving to students’ reasoning about a disturbed ecosystem (a lake where the nutrients or the salinity of the water were increased and subsequently decreased due to human actions - item 4), we note the following. The prediction of ‘full recovery’ of the initial state, due to a ‘recovery process’ or ‘recovery mechanisms’, became significantly less frequent in the post-test (Figure 2). In students’ own words:

- *“The enrichment of the lake with nutrients will cause the increase of phytoplankton and, consequently, the increase of zooplankton, fish and sea birds. However, when we remove the extra nutrients from the lake, the phytoplankton will eventually decrease. Therefore, the zooplankton will decline, since their food will have been decreased, and the same will also happen with the fish and the sea birds, until the lake ecosystem moves back to normal.”* (pre-test)
- *“When the salinity gets back to its initial level, the populations of organisms which live in the lake will get back to their initial numbers. This happens because after the salinity is restored, the balancing loop existing in the lake will reverse the changes that took place because of the human intervention and the organisms living in the lake will come back to normal.” (*post-test)

On the contrary, the prediction of ‘no recovery’, due to ‘side’ or ‘long-lasting effects’ of the disturbance and certain ‘feedback-change’, appeared so frequently that it became the dominant one, although it was very rare in the pre-test (Figure 2). This outcome was not desirable either. In students’ own words:

- *“Although the nutrients are restored to their initial number, the animal and plant populations have been through changes that challenge their survival. I think that the lake will be different than its initial state even after the nutrients restore.”* (pre-test)
- *“Before the sewage inflow, the lake is stable because of the existence of balancing loops. The sewage inflow causes the water salinity of the lake to increase and the balancing loops break. Some species populations increase and some other decrease. The ecosystem’s regime shifts. Even when people manage to restore the water salinity to the initial level, the ecosystem is not going back to its initial state because the populations have been seriously disturbed.”* (post-test)

Nevertheless, the idea that a reverse shift might either occur or get hindered or even blocked by side effects, *did* lead some students to the prediction of a contingent future for the disturbed ecosystem (Figure 2). In their own words:

- *"Nevertheless, this increase of the salinity of the water may have caused side problems that are not dealt with by simply restoring the salinity to the previous level. If this is the case, then restoring the salinity of the water will not make the lake return to its initial natural state"*. (post-test)

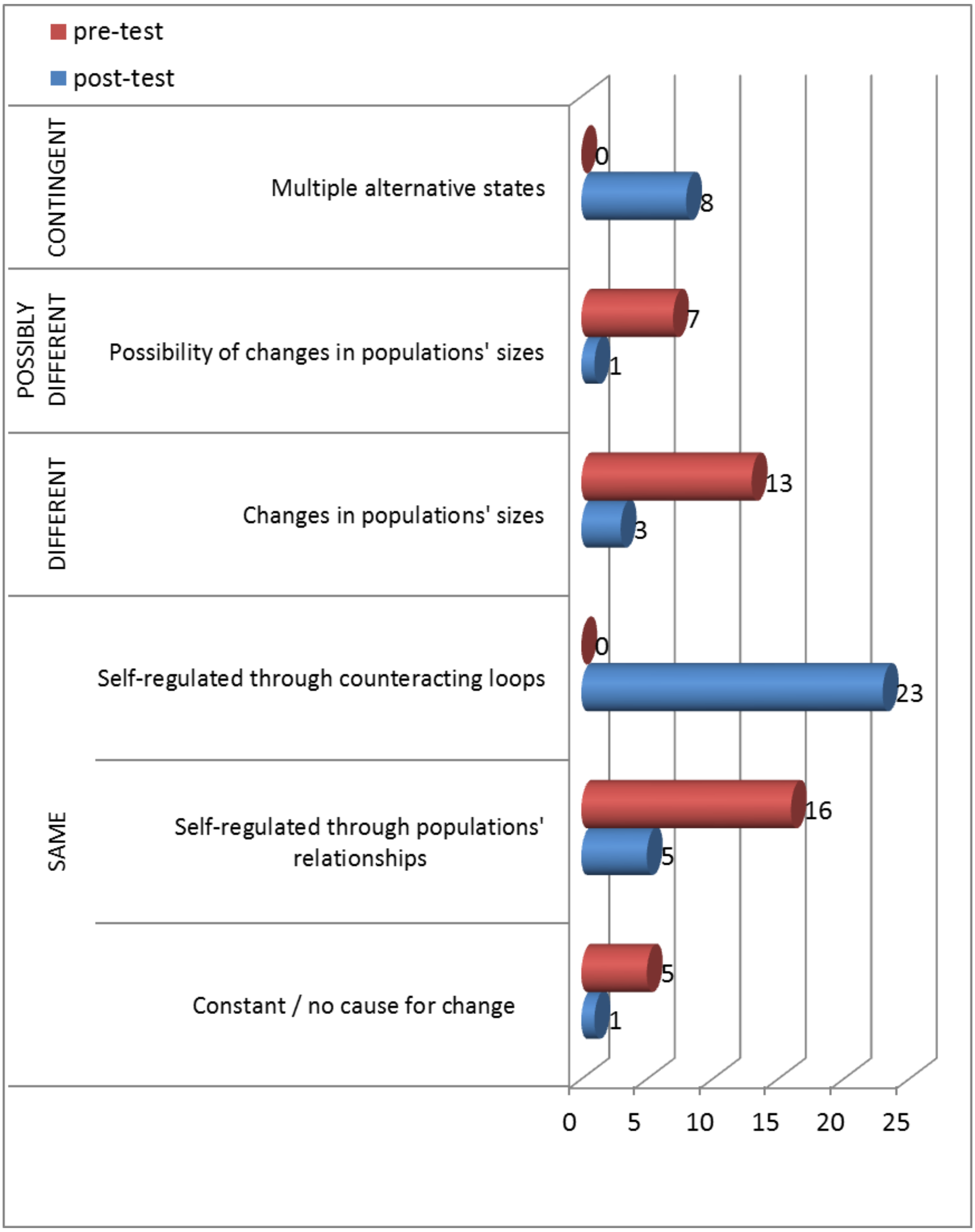

Figure 1. Categories of predictions/justifications about a protected ecosystem (item 1).

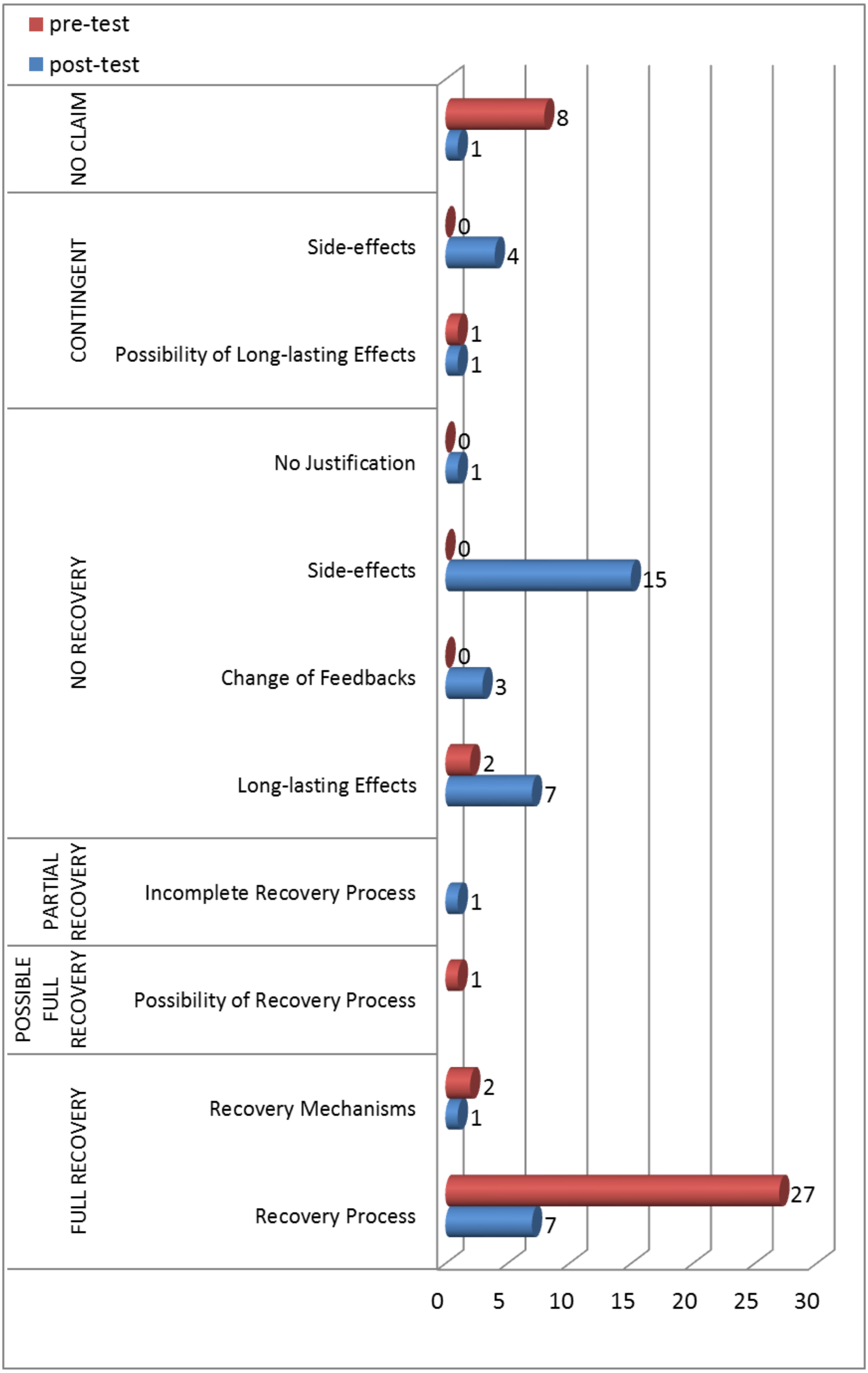

Figure 2. Categories of predictions/justifications about a disturbed ecosystem (item 4).

DISCUSSION

We may argue that the idea of 'multiple natural states' ('LO1') *did* serve as justification for the contingent behaviour of a protected ecosystem *only* for a few students. Moreover, it should be noted that the idea of the counter-acting or balancing loops (part of 'LO2') appeared to be misleading for almost half of the students who drew on them to claim the stability of the protected ecosystem. This undesired claim may also be attributed to our first *'NetLogo'* model. The reason is that 'NM1-Forest' may have emphasized disproportionally the possibility of recovering initial state while simulating an externally undisturbed forest with internally triggered changes. Thus, it may be purposeful to develop 'sub-models' of 'NM1'; namely, alternative models that would present the trajectory of the forest as contingent on certain conditions, like for instance the initial size of its populations. In other words, it might help if students were confronted with one possible trajectory of the externally undisturbed forest through one 'sub-model', and with another possible trajectory through a second 'sub-model', differing from the first in some initial condition.

Doing so, special attention should be given to the idea that the states deriving from the different trajectories need to be considered as equally 'normal' or 'natural'. This is rather important since students tend to believe that there is only *one* natural state for an ecosystem and it needs to be maintained. So, the ecosystem may pass to another state, but "*because of the balancing loops…, the situation will eventually change back and everything will be normal again"*. Moreover, the ways that the balancing (and reinforcing) loops appear in our learning environment should be reconsidered. The apparently over-estimated power of the balancing-loops needs to be challenged properly.

Moreover, we may argue that the ideas according to which shifts between alternative states may be irreversible ('LO4') or reversible with hysteresis ('LO5') *did* serve as justification for the contingent behaviour of a disturbed ecosystem for a few students, as well. When reasoning in this context, students appeared to have moved from the *always*-recovering nature to the *never*-recovering one. This may suggest a desired retreat of the idea of the 'balanced nature', but is also indicative of students' difficulties in understanding the *flux* of nature through the ideas of 'LO4' and 'LO5'.

These difficulties did not seem to be addressed properly in the first version of our learning environment. The models 'NM2-Lake' and 'NM3-Lake', that correspondingly simulate a lake with externally triggered changes, may have over-emphasized the possibility of *non*-recovering initial state or having tremendous difficulties in doing so. Thus, both these models need to be reconsidered. Again the idea of developing two 'sub-models' in each case seems interesting. More specifically, it might help if students were confronted with one possible trajectory (no recovery) of the ecosystem that has been externally disturbed through one 'sub-model', and with another possible trajectory (recovery) through a second 'sub-model', which would differ from the first in some initial condition. This strategy seems to offer a possibility to deal with the over-estimation of non-recovery as well, and will be tested in the second version of our learning environment.

In summary, taking the above into account, we will attempt to design a new version of the learning environment to deal more effectively with students' difficulties in understanding how nature works if protected or disturbed. Introducing 'sub-models' like the ones discussed above and challenging the 'power' of balancing or counteracting loops with a more careful presentation of their possible contribution to the function of the ecosystems, may lead us to better results in the second cycle of the research.

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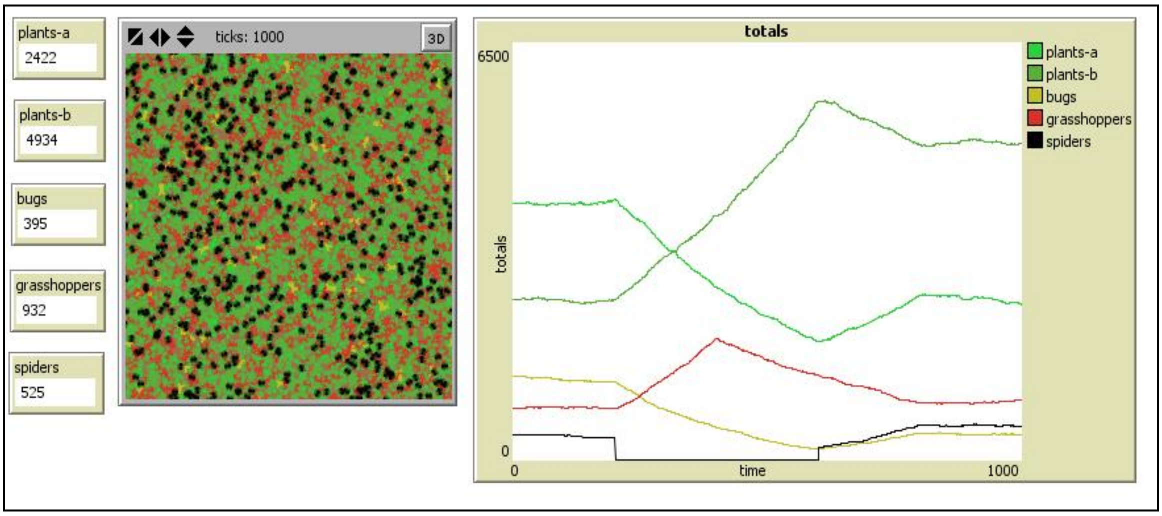
APPENDIX



plants-a 2422

plants-b 4934

bugs 395

grasshoppers 932

spiders 525

Figure 3. Net Logo Model 'Meadow': removal / re-introduction of spiders.