CAN THE IDEA OF ‘BALANCE OF NATURE’ BE EFFECTIVELY CHALLENGED WITHIN A MODEL-BASED LEARNING ENVIRONMENT? INSIGHTS FROM THE SECOND CYCLE OF DEVELOPMENTAL RESEARCH

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Abstract
This paper reports on the second cycle of developmental research aimed at designing a learning environment that can support non-biology-major students in (a) challenging the idea of ‘the balance of nature’ and constructing an up-to-date understanding of ecosystem function, and (b) using this understanding to enhance context-free ideas that underlie systems thinking. Here, we focus on whether and how students’ reasoning about ecosystems’ responses to disturbance or protection has been altered after their engagement with the second version of our learning environment, and whether the problems identified in implementing the first version of it were effectively dealt with. Considering social constructivism and a problem-posing approach, we developed a CSCL environment to highlight ecosystems’ contingent behavior through the idea of ‘resilience of nature’. Thirty-four first-year students were introduced to the assumptions of the idea of ‘resilient nature’ in five 2-hour sessions, 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 unpredictability as a substantial feature of ecosystems was reached by most students, while the problems identified in the first version of our learning environment were handled rather successfully.

1. Introduction

Research on the ways in which students reason about ecosystems and in particular, ecosystem responses to human-driven disturbance or protection, has revealed a widespread belief in the 'balance of nature' (Zimmerman & Cuddington, 2007). The idea of 'balanced nature' is a long-held, popular assumption about the natural world, which implies a predetermined order and stability, assured by the will of a divine power or nature itself (Cooper, 2001; Cuddington, 2001; Kricher, 2009). This view has been criticized quite strongly as not being representative of natural systems (Cooper, 2001; Cuddington, 2001; Kricher, 2009), but it seems to dominate public perception (Ladle & Gillson, 2008), school science (Jelinski, 2005; Korfiatis, Stamou, & Paraskevopoulos, 2004; Westra, 2008), and students' reasoning about ecosystems' responses to human-driven disturbance or protection (Ergazaki & Ampatzidis, 2012).

It is worth noting that a belief in the 'balance of nature' may hinder environmental awareness. Believing the 'initial-state recovery' assumption of the outdated cybernetic view of ecosystems may lead to an underestimation of the consequences of disturbances to them (Westra, 2008). Moreover, such a belief seems to hinder conceptual understanding as well. It obviously opposes the current idea of 'nature's resilience', which (a) favors contingency over purpose and order, (b) suggests that ecosystems function in multiple alternative states which are self-organized through feedback, (c) assumes that ecosystems shift between these states in abrupt—and not necessarily reversible—ways (Gunderson & Holling, 2002; Holling, 1973; Scheffer, 2009), and (d) seems to offer a promising context for fostering systems thinking skills, which are considered crucial for all aspects of life (Boersma, Waarlo, & Klaassen, 2011).

Thus, our study addresses the question of whether it is feasible to design a learning environment that can support non-biology-major students in (a) challenging the idea of the 'balance of nature' and constructing a meaningful, up-to-date understanding of ecosystems' functions, and (b) using this understanding to enhance context-free ideas, such as interdependent and circular causality, which underlie systems thinking. In this paper, we are particularly concerned with identifying (a) whether and how students' reasoning about ecosystems' responses to human-driven disturbance or protection has been altered within the second version of our learning environment, and (b) whether the modifications we made to the first version of this learning environment, such as introducing the use of 'two-version models', were effective. Therefore, the questions here are:

(a) What kind of predictions do students make about the future of disturbed or protected ecosystems and how do they justify them before and after their participation in the second version of our learning environment?
(b) Are the problems identified in implementing the first version of the learning environment, such as overestimation of the power of balancing loops, effectively dealt with in the second version?

2. Methods

2.1 Study overview

In this developmental research study (Akker, Gravenmeijer, McKenney, & Nieveen, 2006), we drew upon social constructivism (Vygotksy, 1978) and a problem-posing approach (Klaasen, 1995) to design a computer-supported, collaborative learning environment that aims to support non-biology majors in challenging the idea of the ‘balance of nature’ and replacing it with the idea of ‘resilience of nature’. We also developed a pre/post-questionnaire with open-ended items, followed by short interviews when needed, to collect data about the effectiveness of our learning environment. Finally, we analyzed students’ responses using the qualitative analysis software NVivo and tested for the statistical significance of their progress using the quantitative analysis software SPSS.

2.2 The participants

The second cycle of the research, upon which we report here, was carried out with some of the 160 first-year students of educational sciences at the University of Patras (aged 18–19 years), who were enrolled in an optional ecology course offered by the second author. More specifically, those students who attended the course classes on a regular basis were asked to consider the possibility of taking part in the study, after they had been (a) thoroughly informed of its goals and time schedule, and (b) reassured that they could pull out at any time for any reason. Thirty-four students volunteered to participate. They (a) had basic ecological knowledge from a university entrance course, (b) were familiar with computers and group work, and (c) were rather active in terms of raising and answering questions in the course’s regular classes, thus showing interest in its content.

2.3 The learning environment

The learning environment aims to highlight the contingent behavior of ecosystems through the basic assumptions of the idea of ‘resilient nature’. More explicitly, the learning objectives (LOs) have to do with understanding these assumptions (LO1–LO4), and with using them to (a) challenge the notion of balance as an inherent feature of nature and (b) move to the notion of contingency (LO-contingency).

More specifically, the LOs consisted of:

- LO1: Ecosystems may have multiple alternative states.
- LO2: Each state is self-organized through feedback which changes abruptly at tipping points.
- LO3: Shifts between alternative states may be irreversible or reversible based on initial conditions or handlings.
- LO4: Reversing the factor that caused the shift does not necessarily return the ecosystem to its prior state.
- LO-contingency: Natural systems show contingent—and not predetermined—behavior (‘resilient nature’ vs. ‘balanced nature’).

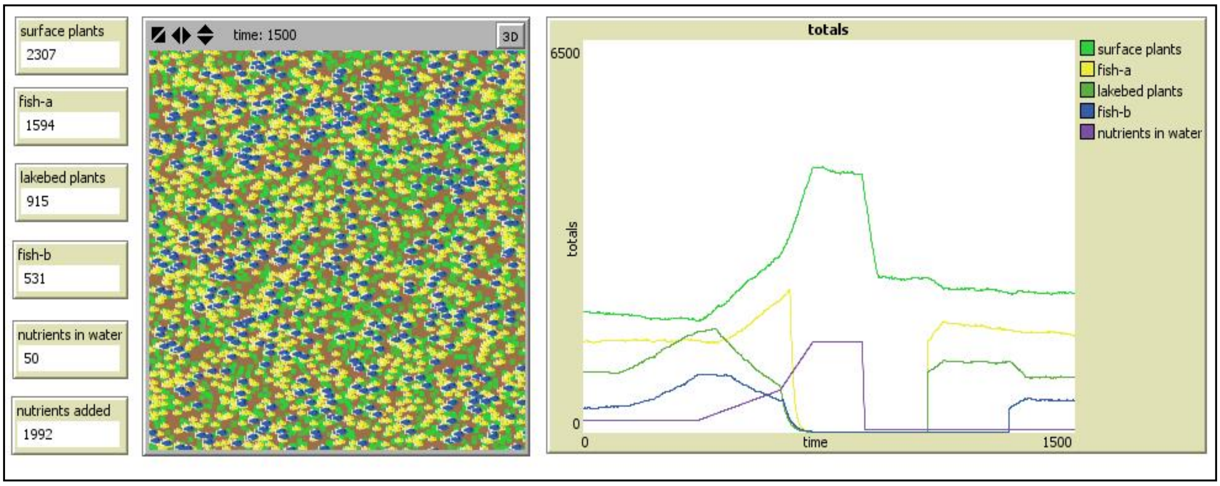
Students were introduced to the assumptions of the target idea in five 2-hour sessions of an optional ecology course. The four models that we developed using the NetLogo software (Wilensky, 1999) to pursue the LOs were based on the findings of current ecological research, and they simulated terrestrial or aquatic ecosystems faced with internally or externally triggered changes (NetLogo models—NMs). The models' interface included three elements: (a) a series of boxes depicting population size (i.e. the number of individuals), as well as the level of certain abiotic factors (e.g. nutrients) where called for, (b) a ‘simulation window’ depicting the individuals of the different populations in different shapes and colors, giving the students a relatively concrete visual representation of what happens in the ecosystem with time, and (c) a ‘graph window’ depicting the changes in population size and the levels of certain abiotic factors with time, providing the students with a graphical representation of the trajectory of the ecosystem that they are actually required to explore (see Figure 1 from left to right).

The results from the first research cycle, in which we implemented the first version of our learning environment, seemed to underline a rather problematic effect of some models on students' understanding. The model 'NM1-Forest', which simulates a protected forest that undergoes internally triggered changes, may have overemphasized the possibility of recovery to the initial state, while 'NM2-Lake' and 'NM3-Lake', which simulated a lake that undergoes a human-driven disturbance, may have overemphasized the possibility of not recovering to the initial state or facing significant difficulties in doing so (Ampatzidis & Ergazaki, 2014).

Taking this feedback into account, we came up with the 'two-version model' idea: this time, each model had two different versions showing two different trajectories of the ecosystem, depending on its initial conditions or on certain human actions in the recovery plan. Students collaborated in groups of three, and half of the triads explored one version while the other half explored the other version. The two different trajectories simulated by each model were discussed with the whole class at the end of the sessions.

More specifically:

- Session 1 – NM1-Forest: the model simulated the maturation of a tree species in a forest (Gunderson, Allen, & Holling, 2010) that was inhabited by two plant species (spruces and bushes) and three animal species (budworms, rabbits and passerines). In one version, the ecosystem's state did not shift, whereas in the other version, the bushes and rabbits died out. The focus here was on LO1, LO2 and LO-contingency.
- Session 2 – NM2-Lake: the model simulated an inflow of nutrients into a lake (Scheffer, 2009) that was inhabited by phytoplankton, zooplankton, one species of sea plant and two species of fish. In one version, the ecosystem's state did not shift, whereas in the other version, all populations died out apart from the phytoplankton. The focus here was on LO1–LO4 and LO-contingency.
- Session 3 – NM3-Lake: the model (Figure 1) simulated an inflow of nutrients into a lake, their subsequent removal, and the performance of other corrective actions to restore the lake (Scheffer, 2009). The lake was inhabited by two plant species and two fish species. In one version, the ecosystem shifted back to its original state, whereas in the other version, this was not possible. The focus here was on LO1–LO4 and LO-contingency.
- Session 4 – NM4-Meadow: the model simulated the removal and subsequent reintroduction of an animal species (spiders) from a meadow (Schmitz, 2010). The meadow was inhabited by two plant species and three animal species (grasshoppers, spiders and bugs). In one version, the ecosystem shifted back to its original state, whereas in the other version, this was not possible. The focus here was on LO1–LO4 and LO-contingency.



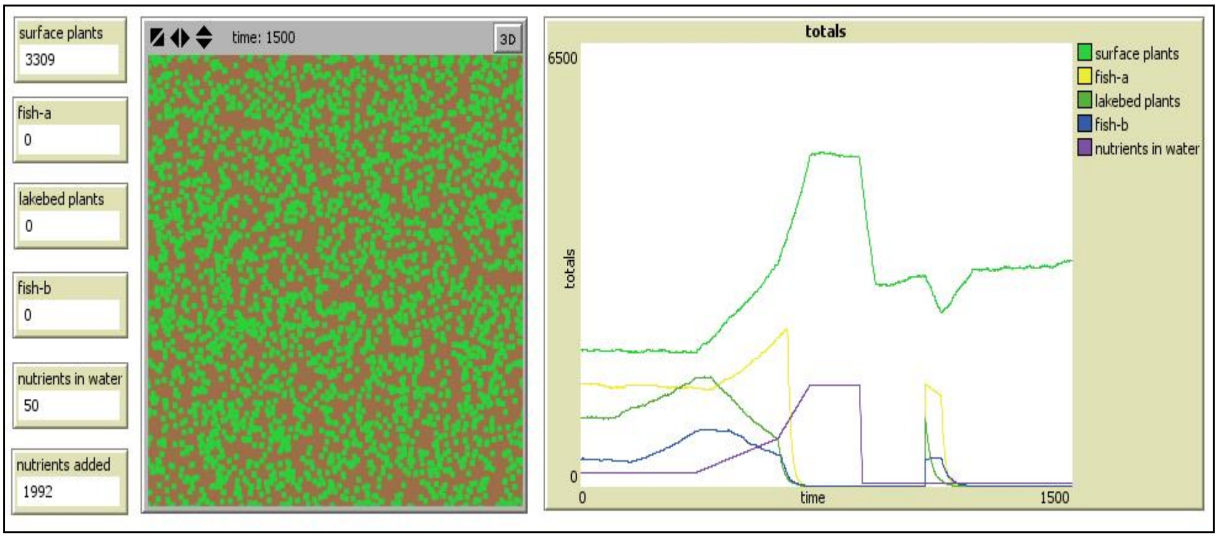


Figure 1. The two-version NM3-Lake model: inflow of nutrients, subsequent removal and additional corrective actions (version 1 at the top, version 2 at the bottom).

Finally, in the fifth session, students were engaged in reasoning about ecosystems' behavior through 'landscape models' made from plasticine cardboard and hands-on activities concerning systems thinking.

2.4 The pre/post-questionnaire

Students were administered a pre/post-questionnaire after it was explained to them that this was not an exam but an opportunity to give us valuable insight into their own understanding of nature. Its first part included five open-ended items on the behavior of protected or disturbed ecosystems. The pre/post items were equivalent and all of them—except for item 2—aimed to probe specific target assumptions as justifications for the contingency ($_{\text{J-contingency}}$) of the ecosystems' behavior (see LO1–4$_{\text{J-contingency}}$).

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 – 'feedback': students were asked to explain the control of population size in a lake/swamp through feedback-mediated self-organization, and the loss of population control through feedback change at a tipping point. The focus here was on LO2.
- 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 LO3–4$_{\text{J-contingency}}$.
- Item 4 – 'disturbed ecosystem–abiotic change': students were asked to reason about the future of a lake where the nutrients in the water or salinity of the water were (a) increased due to human activity, which led to the extinction of an animal species, or (b) restored to their initial value, followed by reintroduction of the extinct species. The focus here was on LO3–4$_{\text{J-contingency}}$.
- 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 LO1–4$_{\text{J-contingency}}$.

The questionnaire was first administered to non-participating students with a 'think-aloud' protocol and elaborated accordingly. Finally, the first author read all of the responses as soon as the students had completed the questionnaire and carried out short interviews with those whose responses needed clarification. In this report, we are only concerned with items 1 and 4.

2.5 The analytical procedure

Students' responses to the pre/post-questionnaires and relevant notes from the interviews, where applicable, were transcribed and coded within NVivo, one of the most widely used softwares for the analysis of qualitative data (Gibbs, 2005). What we actually did was to create a series of data-driven categories by reading students' responses to each task and coding their predictions as well as their justifications. In other words, our coding scheme was derived through 'open coding' (Gibbs, 2005) and it was divided into two parts: (a) students' 'predictions' about the future of the ecosystem in question (e.g. 'full recovery', 'possible full recovery', 'same picture'), and (b) students' 'justifications' for what they had predicted (e.g. 'unpredictable factors', 'possible side effects', 'possible differences in handlings'). The coding was performed by both authors with satisfactory agreement: Cohen's Kappa with regard to items 1 and 4 was estimated at 0.88.

Moreover, to test students' progress and its statistical significance, we developed a scoring grid for their responses to each item of the questionnaire (Table 1). The score of each response was the sum of two sub-scores: one for the prediction about the future of the ecosystem in question and another for the justification provided for that prediction. More specifically, the prediction of an 'unpredictable picture' was assigned the highest score, while the predictions of 'same picture'/'different picture' and 'full recovery'/'no recovery' were scored lowest. Similarly, each justification was assigned a score depending on the level of understanding that it showed (Table 1). It should be noted that the scoring grid was developed so that predictions contributed more than justifications to the total score. Thus, satisfactory predictions with non-satisfactory justifications got a higher score than non-satisfactory predictions with satisfactory justifications. Finally, responses with no predictions were not scored at all and responses with unjustified predictions were scored according to the prediction only.

Table 1. The scoring grid.

Items	Predictions	Prediction score	Justifications	Justification score	Total score
Item 1	Unpredictable/ contingent picture	3	Possible tipping point reached	0.5	3.5
			Possible feedback change	0.5	3.5
			Unpredictable factors	0.25	3.25
	Possible different picture	2	Possible changes in population sizes	0.5	2.5
			Possible changes in environmental factors	0.5	2.5
	Same picture	1	Self-regulated populations if not disturbed by humans	0.5	1.5
	Different picture	1	Changes in population sizes	0.5	1.5
			Changes in environmental factors	0.5	1.5
Item 4	Unpredictable/ contingent	3	Possible tipping point reached/feedback change	0.75	3.75

	picture		Possible tipping point reached	0.5	3.5
			Feedback	0.5	3.5
			Possible differences in recovery handlings	0.5	3.5
			Possible side effects	0.5	3.5
	Possible full recovery	2	Possible recovery process	0.25	2.25
	Full recovery	1	Recovery process	0.25	1.25
	No recovery	1	Changes in populations' relationships	0.5	1.5

3. Findings

Regarding students' reasoning about the future of a protected ecosystem such as a terrestrial or aquatic national park (item 1), we note that in the post-test students found the idea that the protected ecosystems remain unchanged *less* appealing. More specifically, the prediction of 'same picture' based on 'self-regulation of populations in the absence of human disturbance' became *less* popular in the post-test (Figure 2). In the students' own words:

- *"Since the forest is protected from human and natural disturbances, some years later there will be no change, because the environmental conditions are controlled and ideal for the well-being of the flora and fauna."* (pre-test)

Moreover, the prediction of a 'different picture' due to changes in 'population sizes' or 'environmental factors' became *less* popular in the post-test as well (Figure 2). In the students' own words:

- *"There will be more animals and plants in this forest some years later since there are people who check and protect their well-being."* (pre-test)
- *"If the environmental conditions change and, for example, extreme high or low temperatures are recorded, in that case plants won't survive and this will also make the animals leave the forest."* (pre-test)

In contrast, the prediction of a 'possibly different' picture because of possible changes in 'population sizes'/'environmental factors' became *more* frequent in the post-test (Figure 2). In the students' own words:

- *"As we know, there is no human activity in this aquatic park and all of the organisms live undisturbed. However, some years later, the size of each population may change. My conclusion is that, although the ecosystem is protected from human disturbances, it may be stable or it may change."* (post-test)
- *"Since the aquatic park is protected from human disturbances, there won't be any changes, unless there is a change of temperature or weather conditions, which could cause the water level to get lower, and change the number of organisms."* (post-test)

Finally, some students supported unpredictable/contingent behavior for the ecosystem, justified by unpredictable factors, feedback changes or populations reaching a tipping point (Figure 2). In their own words:

- *"We cannot be sure about the state of this aquatic park some years later. That is because the human activity, which is forbidden, is only one of the factors that could make it shift to* *an alternative state. Other factors, such as competition among different species, access to sunlight, available oxygen, etc., could also influence its state."* (post-test)

- *"Some years later, the ecosystem will either be in the same state, balanced by balancing loops, or it will have shifted to an alternative state if the balancing loops have stopped functioning and new reinforcing loops have been established."* (post-test)
- *"We cannot be sure about how this aquatic park will look like some years later. Even without human disturbance, there is a chance of changes due to natural reasons. However, we cannot be sure whether these changes will reach a tipping point leading to a shift of the state of this aquatic park."* (post-test)

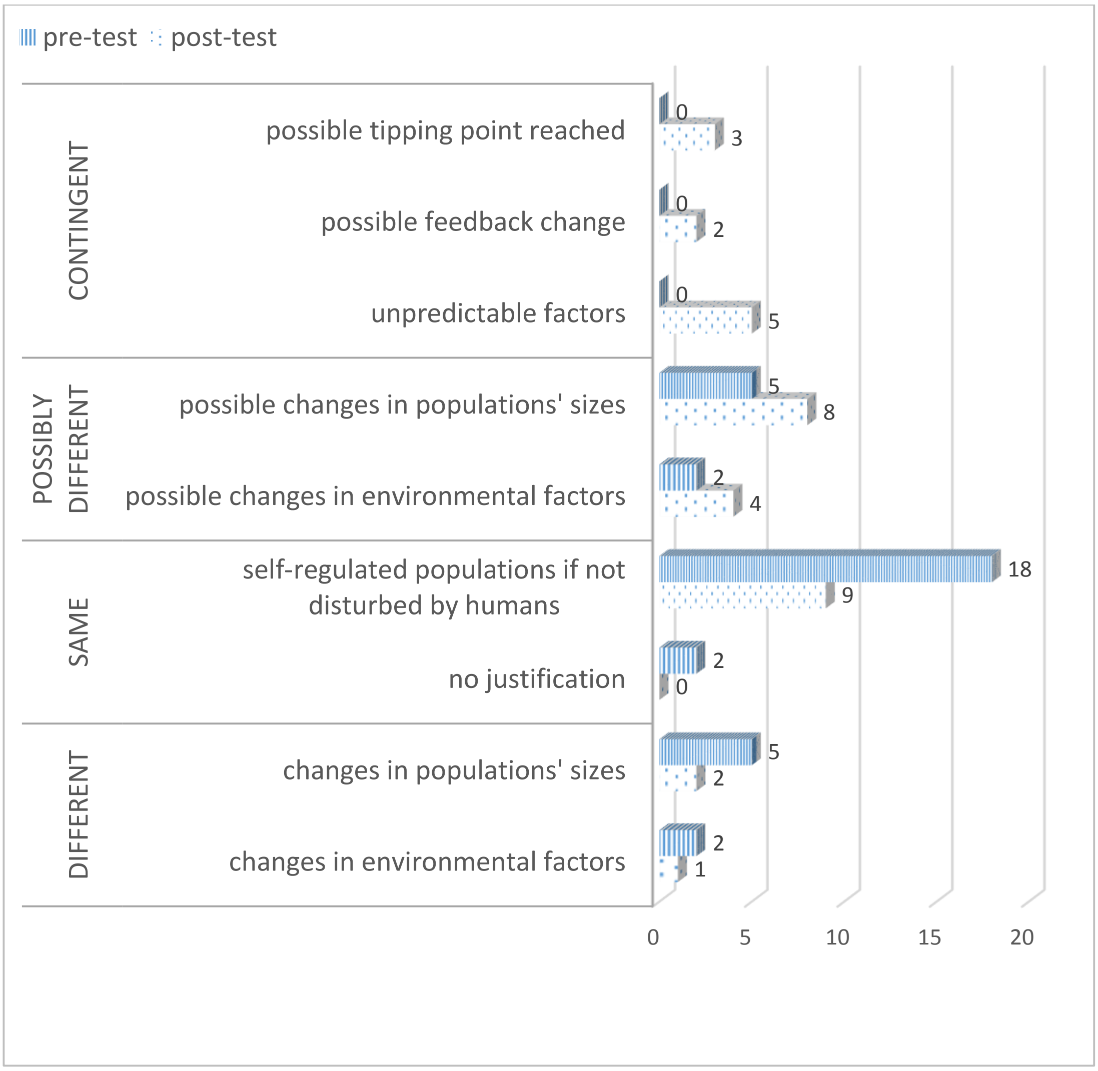


Figure 2. Categories of predictions/justifications pertaining to a protected ecosystem (item 1).

Moving on to students' reasoning about a lake where the nutrients or salinity of the water were increased and subsequently decreased due to human actions (item 4), we note that the prediction of 'full recovery' of the initial state became significantly *less* frequent in the post-test (Figure 3). In the students' own words:

- *"Zooplankton will feed on phytoplankton. Fish will feed on phytoplankton and sea birds will feed on fish. Thus, the lake will come back to its original condition and the food chain will continue normally."* (pre-test)

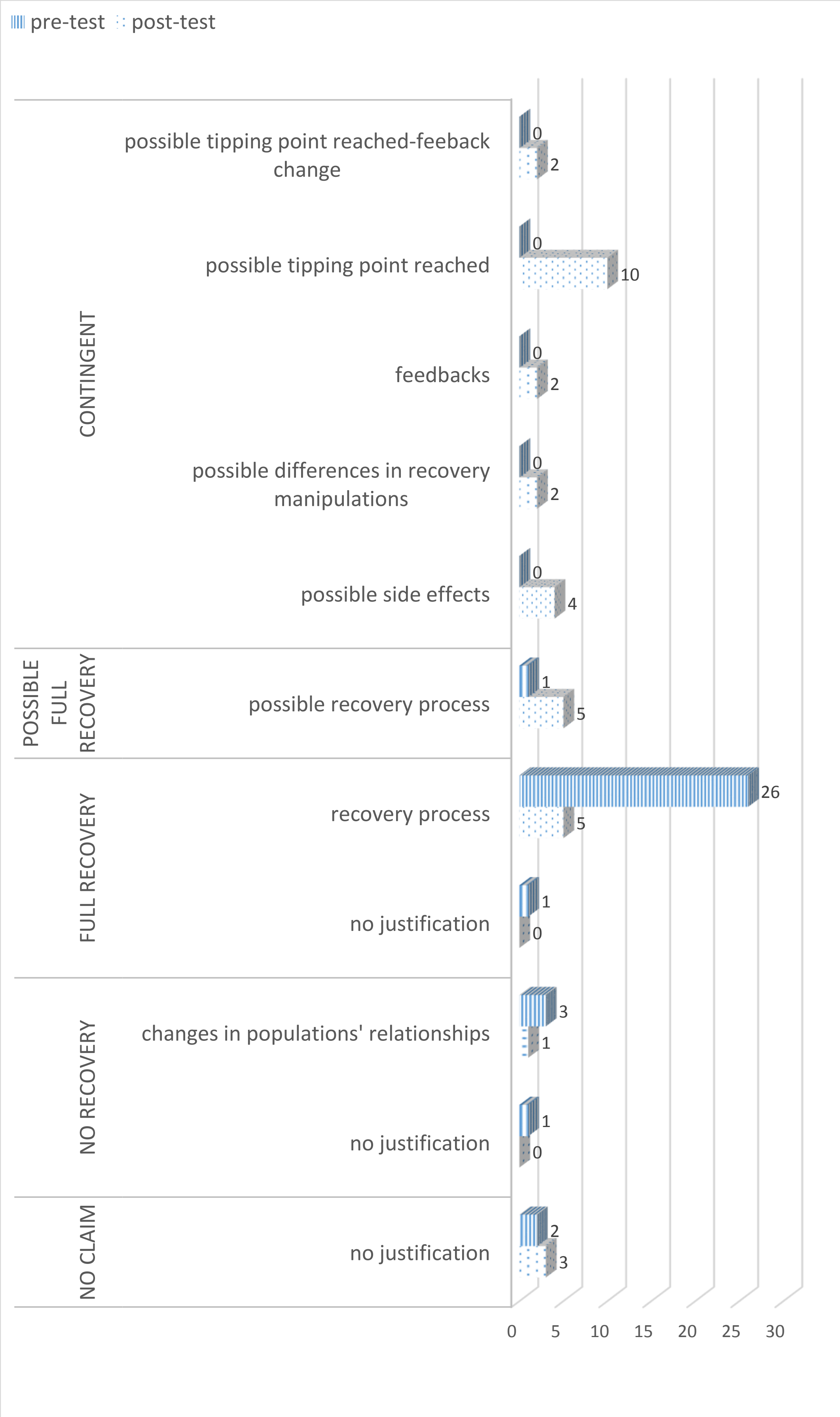


Figure 3. Categories of predictions/justifications pertaining to a disturbed ecosystem (item 4).

Moreover, the prediction of 'no recovery' because of 'changes in population sizes' became *less* popular in the post-test as well (Figure 3). In the students' own words:

- *"The nutrient inflow will cause an increase of the algal population and consequently the balance in the lake will change. When the nutrients of the lake get back to normal, the algae will die out since their now larger population has increased needs for nutrients. Thus, the lake will not recover its original state."* (pre-test)

In contrast, the prediction of a 'possible full recovery', based on a 'possible recovery process' became *more* frequent in the post-test (Figure 3). In the students' own words:

- *"After the restoration of the salinity of the lake and the reintroduction of the missing fish population, the lake will try to recover, under the function of balancing and reinforcing loops. We cannot be sure that this recovery process will restore the lake to its original state."* (post-test)

Moreover, several students argued that the disturbed ecosystem would have unpredictable/contingent behavior by mostly considering the unpredictable case of a population reaching a tipping point between the disturbance and restoration time (Figure 3). In their own words:

- *"After the restoration of the lake's salinity and the reintroduction of the missing fish population, the lake may recover its original state or not; it depends on whether some population reached a tipping point during the time of the human disturbance which may have shifted the lake's state to a point that does not favor the recovery of the missing fish population."* (post-test)
- *"We cannot be sure whether the lake will show the same picture as at the beginning or not. If during the time we caused the increase of the salinity and the subsequent increase and decrease of populations, some of them reached a tipping point, the lake could shift to an alternative state. On the contrary, if this was not the case, then the restoration of the salinity and the reintroduction of the missing fish population will bring the lake back to its original state."* (post-test)

Finally, a Wilcoxon signed-rank test was performed to determine whether the scores assigned to students' responses in items 1 and 4 according to their level, differed in a statistically significant way between the pre-test and post-test. For both items, the score difference between the pre- and post-test was found to be statistically significant (item 1: $Z = -3.864$, $p < 0.01$; item 4: $Z = -4.294$, $p < 0.01$).

4. Discussion

LO1 served as a justification for the unpredictable/contingent behavior of a protected ecosystem for 10/34 students. Taking into account also those who claimed a 'possible different picture', we may argue that after their exposure to the second version of the learning environment, 22/34 students *did* recognize a certain degree of unpredictability in the behavior of a fully protected ecosystem. Comparing these results to the ones from the first version of the learning environment (22/34 vs. 9/41), one may claim that our modifications were effective (Ampatzidis & Ergazaki, 2014).

More specifically, it seems that the development of two sub-models for NM1-Forest was effective in supporting students' understanding of the unpredictable behavior of a fully protected ecosystem. During the whole-class discussion at the end of the first session, students had the chance to realize that the trajectory of the forest in their simulations might be contingent on some initial conditions (e.g., the initial size of a plant population). This seems to have helped them move from the idea of a ‘never-changing’ ecosystem to the idea of unpredictability as an inherent feature of ecosystems.

Furthermore, in an effort to challenge the apparently overestimated power of the balancing loops that was somewhat promoted in the first version of the learning environment (Ampatzidis & Ergazaki, 2014), this time we connected (a) the balancing loops with the *temporal* balance of the ecosystem, and (b) the stopping of the balancing loops and the subsequent initiation and function of the reinforcing ones with the shift of the ecosystem to an alternative state. These modifications aimed to help move from (a) an arguably misleading representation of the balancing loops, and (b) a rather vague idea according to which each stable state is organized through specific balancing and/or reinforcing loops and when these change, the ecosystem may shift to a different stable state, to a more specific and accurate presentation of the role that feedback loops play in ecosystems. As a result, only 9/34 students predicted a ‘same picture’ of the ecosystem in the post-test with no one drawing on the balancing loops, which was actually the case for almost half of the students in the first cycle of research (Ampatzidis & Ergazaki, 2014).

LO3 and LO4 served as justifications for the contingent behavior of a disturbed ecosystem for most of the students (20/34). Again, it seems that being exposed to the different versions of each model and the whole-class discussions helped students move from the idea of ‘always-recovering nature’ to that of ‘unpredictable nature’.

More specifically, it seems that the development of sub-models for NM2-Lake, NM3-Lake and NM4-Meadow helped students understand the unpredictable behavior of disturbed ecosystems. During the whole-class discussions at the end of the relevant sessions, students had the chance to realize that the trajectories of the simulated ecosystems may be contingent on some initial conditions [for instance, the number of nutrients introduced in a lake (NM-2) or the initial number of plants in a meadow (NM-4)], or to differences in the handlings during the effort to restore the ecosystem (NM-3). Once again, this seems to have helped the students move from the idea of an ‘always-recovering’ ecosystem to the idea of unpredictability as an inherent feature of ecosystems.

Finally, the introduction of sub-models and whole-class discussions about them in the second version of the learning environment seemed to be effective in dealing with the overestimation of non-recovery in the first version. This time, the idea of never-recovering nature was evidently less appealing than it was in the first cycle of research (1/34 vs. 26/41) (Ampatzidis & Ergazaki, 2014).

In summary, it seems that our modifications of the first version of our learning environment were effective, and the students who participated in the implementation of its second version were efficiently supported to build an understanding of how nature works in the case of protection or disturbance. The third version of our learning environment will be designed in line with these results, and it will be implemented and tested during the third cycle of the research.

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