The Use of Qualitative Reasoning Models of Interactions Between Populations to Support Causal Reasoning of Deaf Students

[1]Paulo SALLES, [2]Heloisa LIMA–SALLES, [3]Bert BREDEWEG
{[1]Institute of Biological Sciences, [2]Department of Linguistics},
University of Brasília, Campus Darcy Ribeiro, 70.919-900 Brasília, DF, Brazil;
[3]Human Computer Studies Laboratory, Faculty of Science, University of Amsterdam,
Kruislaan, 419, Matrix I, 1098 VA Amsterdam, The Netherlands

{hsalles@unb.br; psalles@unb.br; bredeweg@science.uva.nl}

Abstract

Making inferences is crucial for understanding the world. The school may develop such skills but there are few formal opportunities for that. This paper describes an experiment designed to investigate the use of qualitative reasoning models to support deaf students in making inferences about the behaviour of populations in interactions such as commensalism, amensalism, and predation. The experiment was done in two sessions. In both, the teacher presented the concepts, which were translated to the signed language, and at the end the students answer to a test, consisting of objective questions and a written essay. In the second session qualitative models about the interactions were used to show the structure of the two populations system and the dynamics of the system over time. Statistical analysis showed that the use of qualitative models had a significant positive effect on the performance of the students. They gave more correct answers to objective questions and produced less trivial conclusions in their essays. We are confident that qualitative models have an important role to play in their scientific education and in the acquisition of Portuguese as a second language.

1 Introduction

Inferences are fundamental for the comprehension of the world. It is a natural ability, but education may improve this capacity, by rendering it explicit. For those with special needs, like deaf students, there are some additional requirements, as Brazilian deaf students are being integrated in the classroom with non-deaf students and have to acquire Portuguese as their second language, being the Brazilian Sign Language (LIBRAS) legally recognized as their first language. Beside difficulties they have with attending the courses given in Portuguese and not always translated to LIBRAS, additional problems arise due to the absence of appropriate educational instruments, which should heavily rely on a visual pedagogy.

Qualitative Reasoning [Weld and de Kleer, 1990] may be useful in this respect, providing models in which non-technical vocabulary is used and causality is explicitly represented and used to explain the structure and behaviour of physical systems. An exploratory study about the use of qualitative models in science education to support second language acquisition by deaf students is presented in [Salles *et al*., 2004]. The results reported by these authors allow for a correlation between the writing skills of the students and their understanding of a causal model, assessed in activities such as recognizing objects and processes, building causal chains and applying them to a given situation, making predictions about the consequences of changes, and writing an essay about an ecological accident. The work described here further explores the potential of qualitative models to support second language acquisition mediated by science education of deaf students, in particular to support their ability of making inferences.

The goal of the present study is to evaluate the impact of using qualitative models in the representation of causal relations in problems about interacting populations

[Odum, 1985], as addressed in biology classes, taking into consideration the linguistic performance of the deaf students using Portuguese as a second language, in two tests, which include answering objective questions and writing essays. The domain selected for this study, interactions between populations, is a relevant part of the curriculum in secondary schools, being used to explain other aspects of ecological knowledge, for example, food chains and food webs, and offers many opportunities for the students to make inferences.

Two main aspects of the problem are presently addressed. Firstly, we want to assess the impact of using qualitative models in their understanding of the biological interactions and their ability to make predictions about the behaviour of the populations involved in the interactions. This is done by means of statistical tests applied to the answers given by the students in the objective questions. Secondly, we are looking for evidences that the use of qualitative models may improve their ability to use written Portuguese to express causal reasoning. We discuss the linguistic performance of the students in terms of the notion of *relevance*, as formulated by [Sperber and Wilson, 1995]. According to these authors, "relevant information is information that modifies and improves an overall representation of the world". Such a modification is the result of the operation of a deductive device that combines the stock of concepts and newly acquired factual assumptions using a set of deductive rules. Following [Sperber and Wilson, 1995], the human deductive device only operates with interpretive rules to produce *non-trivial* conclusions, that is, implications that explicate or analyse the content of the input, in opposition to *trivial* conclusions, that leave the content of their input assumptions unchanged. In the present study, we evaluate the students' linguistic performance in written essays by assessing the number of trivial and non-trivial conclusions they were able to derive, given the assumption that the use of the latter, as opposed to the former, imply the modification and the improvement of the overall representation of the world, new information being integrated to old one.

The paper is organized as follows: in the next section, we introduce the issue of interactions between populations and explain how these issues were used to assess the use of inferences by deaf students. In section 3 we discuss the methodology used in the experiment. The results are presented in section 4 and, finally, we present a discussion of the results and our final considerations.

2 Interactions between populations: concepts, models and simulations

Interactions between populations of different species are an important subject in ecology and resource management, both for theoretical studies, for example, about the structure of communities, and practical applications, such as for the development of technology related to diseases and agricultural production. Species interactions can be classified according to combinations of the symbols {–,0,+}: the symbol '–' means that one population is negatively affected by the other; '0' means that one population is not affected by the other; and '+' means that one population is positively affected by the other population. Positive and negative effects may be understood as influences on the growth of the population. Accordingly, the symbols {–,0,+} indicate that the population is respectively decreasing, stable or increasing due to the interaction with the other population [Odum, 1985].

Based on these ideas, [Salles *et al*., 2003] present a set of qualitative models about six different types of interactions between populations. These models are meant to be used in educational activities, exploring the explicitly represented causal relations and the possibility of describing structure and behaviour of such systems with non-technical language. In the present study, models about three types of interactions described in [Salles *et al*., 2003] are used to support causal reasoning by deaf students. These interactions are shown in Table 1.

Table 1. Interactions between populations and interpretation of the consequences of such interactions.

Interaction type	Representation	Interpretation of influences
Commensalism	(A,B) = (0,+)	If A changes, then B changes in the same direction; if B changes, A does not change.
Amensalism	(A,B) = (0,–)	If A changes, then B changes in the opposite direction; if B changes, A does not change.
Predation	(A,B) = (+,–)	If A changes, then B changes in the opposite direction; if B changes, then A changes in the same direction.

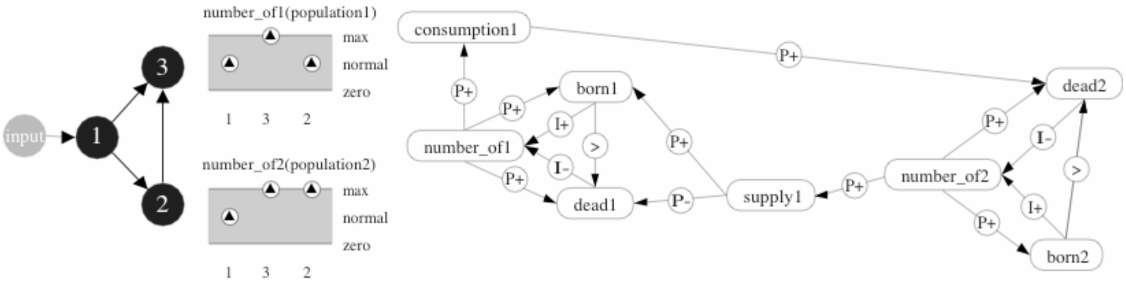

Figure 1: Simulation results for predation visualised by VisiGarp: state-graph (LHS), value-history (middle), and causal-model (RHS), being population 1 the predator and population 2 the prey.

2.1 The ontology and the tools used in the experiment

We adopted the ontology provided by the Qualitative Process Theory [Forbus, 1984]. Accordingly, changes in populations are explained as being the consequence of the effects of other populations on their basic processes of natality and mortality. In this ontology, processes are modelled as direct influences (I+ and I–) of their rates on state variables. The effects of processes propagate to other quantities via qualitative proportionalities (P+ and P–). Figure 1 shows an example of how it was implemented in a qualitative model about predation.

Simulations were run in the qualitative simulator GARP [Bredeweg, 1992] and inspected by using the GUI VisiGarp [Bouwer and Bredeweg, 2001]. A qualitative simulation usually captures a large amount of detailed information. In this study, we explored the simulations using the following features of VisiGarp: (1) E-R diagram showing the system structure (for example, to identify the prey and predator populations and show how they relate to each other); (2) Causal-model (to draw their attention to processes and proportionalities, and to show how causality propagates); (3) State-graph (showing the qualitative distinct states that have been generated for the scenario ('input') that was simulated); (4) Value-history (showing the values of magnitude and the direction of change for each quantity). Figure 1 presents the relevant information typically shown and discussed with learners during the experiment.

In Figure 1 the state-graph (LHS) has three states. The arrows show that state 1 may change into state 2 or state 3, and state 2 may change into state 3. The quantity *number_of1* refers to the size of the predator, and *number_of2* to the size of the prey population. The value-history shows that in state 1 both the predator and the prey have the magnitude *normal* (the position of the circles) and derivative *increase* (arrow pointing up). In state 2 the prey population has increased to value *max*, while the predator is still at *normal*, and both still *increase.* In state 3 the predator has also reached its *max* value. Notice that this behaviour, namely the prey and predator both growing to their highest value, is one possibility for a predation interaction. Other possible behaviours are not shown in Figure 1. The causal-model (RHS) depicts the quantities and their relationships, mainly in terms of influences and proportionalities.

2.2 The hypotheses tested in this study

Based on consultation with teachers and on the experience described in [Salles *et al.*, 2004], we selected a set of seven research questions as the most relevant for this experiment. They are the following:

(RQ1) – Do qualitative models enhance understanding by deaf students of representations of causal relations in interactions between populations?

(RQ2) – In interactions such as commensalism and amensalism, is it easier to the students to predict the effects of changes in the population (A) on the other population (B) in utterances such as [if A is increasing, then B is increasing] than to recognize that changes in the latter (population B) do not influence the former (A), in utterances such as [if B is increasing, A does not change]?

(RQ3) – In predation, is there any difference for the students to predict how changes in the predator population influence the prey population, *e.g.* [if A is increasing, then B is decreasing], than to predict how changes in the prey population affect the predator population, *e.g.* [if B is decreasing, then A is decreasing]?

(RQ4) – Is there any difference in the degree of difficulty of recognizing the effects of positive and negative influences in interactions between populations?

(RQ5) – Considering a food chain such as [A → B → C → D], is it easier for the students to predict changes propagated to the next level above or below, *e.g.* [if C is increasing, then D is decreasing], than to predict changes propagated to organisms placed two or more levels above or below *e.g.* [if B is increasing, then D is increasing]?

(RQ6) – Is there any difference for the deaf students to answer questions if the interacting populations are identified in general terms (such as X and Y) instead of using their names?

(RQ7) – Is it possible to find any difference in the occurrences of trivial and non-trivial conclusions in the written essays after the use of qualitative models?

3 Methodology

This study was developed in a secondary state school[1], with deaf students from the 2nd year. The experiment was run with the support of interpreters of LIBRAS-Portuguese who remained in the classroom during the tutorials. The experiment was set in two parts, with approximately one hour each: (a) a session in 16/11/04, consisting of an oral presentation by a teacher, with an interpreter, followed by Test I; (b) a session in 25/11/04, consisting of an oral presentation, supported by qualitative models, with an interpreter, followed by Test II. During the experiment the teacher presented the effects of the interactions in terms of if – then utterances.

3.1 Subjects

Six deaf students participate in the first session and nine students in the second session[2]. Among them, six students participate in both sessions. Given that there are relatively few deaf people in the population and the number of variables to be considered in studies with the deaf, for example the degree of deafness, age and educational level, the number of subjects selected for this study is in line with similar studies. In fact, the group is as homogeneous as possible. They are fluent in LIBRAS and have some mastering of (written) Portuguese as a second language, given their exposure to this language since their early (formal) education. As shown in the tests, the subjects display different levels of Portuguese, which will be abstracted away, as the present study is not concerned with comparing and (or) establishing their level of proficiency. In fact, the matter of proficiency is a topic on its own, which can be entertained in future work under the same methodology, given the assumption that causal relations (represented in models) allow for a controlled use of the context variables, which is a desirable situation in language testing. It is important to notice that due to the need

3.2 The first session

A tutorial about interactions between populations was given to the students as they normally have in their school classes. It was explained that, although sharing the same space, some species do not interact, while others interact, and these interactions can be classified as beneficial (positive) and harmful (negative), depending on their effects on natality and (or) mortality. Next, the students were exposed to examples of commensalism, amensalism and predation. Finally, concepts related to predation were explored in food chains involving well known animals and plants. The students were familiar with most of the scientific concepts explored in this session, but not with the relation between positive and negative influences and their effects on growth processes.

[1] This study was made in the same school where the experiment described in [Salles *et al.*, 2004] was run.
[2] Three deaf students were involved in the previous study [Salles *et al.*, 2004]. Two of them participated in both sessions and one student participated only in the second session in the present study.

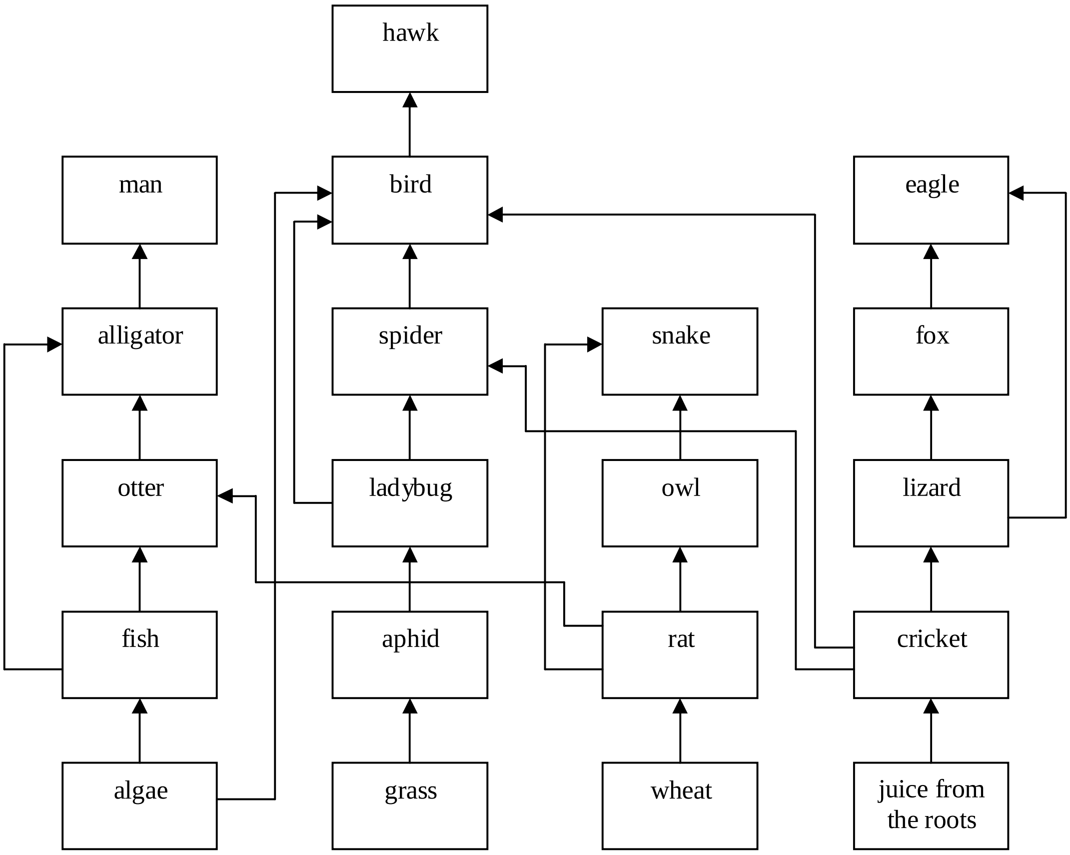

Figure 2: Food web used to motivate the written essays in Test I and Test II. Adapted from [Matsushima *et al*.,1987].

Test I consisted of seven questions, designed to evaluate their ability in the following tasks: (a) to assess basic definitions of species, population and community (I-Q1); (b) to define benefit and harm (I-Q2); both in I-Q1 and Q2 the students should write *correct* / *incorrect* in blank spaces; (c) to identify, in diagrams, the type of interaction by writing the name of the interaction or the sign of the influence in blank spaces (I-Q3); (d) to identify the effects of the interaction in each population by writing *increases* / *does not change* / *decreases* in blank spaces (I-Q4); (e) to identify the consequences of changes in a population in a food chain with 3 organisms (I-Q5); (f) to identify the consequences of changes in a population in a food chain with 6 organisms (I-Q6); both in I-Q5 and I-Q6 the students should write *increases* / *decreases* in blank spaces; (g) to write an essay about the consequences of changes in a food web consisting of two food chains (6 and 5 organisms) (I-Q7). Figure 2 shows the food web used to inspire the students in writing their essays. Different parts of it were used in Test I and in Test II.

Questions I-Q1 to I-Q6 included 30 items for the students to answer. All the questions but I-Q1 asked for predictions about the consequences of a particular change in the system by using inferences as, for example, *IF population X is increasing*, *THEN population Y is decreasing*. In the written essay (I-Q7) the students were asked to explore formulations such as *IF X happens, THEN Y happens*, and *GIVEN THAT X happened, THEN Y will happen*.

3.3 The second session

Initially the students were exposed to a simple qualitative model for introducing vocabulary and modelling primitives. The ‘growing tree’ model was used, in which a tree grows while the area of its shade increases, which in turn causes soil temperature to decrease [Salles *et al.*, 2004]. Next, models about interactions between populations (commensalism, amensalism and predation) were presented to the students. In each case, an example involving well known organisms was given. A slide with a VisiGarp screenshot of the causal model was presented in order to explain how the concepts of benefit and harm were implemented. Finally, a simulation was run and a behaviour path (consisting of two or three states) was selected. Only the values of quantities *number_of* individuals in both populations were shown in the value history diagram. Changes in magnitudes and derivatives were pointed out as the consequences of the interaction. Figure 1 illustrates the material shown to the students. In this session, no comments were made about food chains or food webs, and the students did not play with the models.

Test II consisted of nine questions designed to evaluate the students ability (a) to understand basic modelling primitives (entities, processes, direct influences, proportionalities) (II-Q1); (b) to understand representations of magnitudes and derivatives in the value history diagram (II-Q2); (c) to associate benefit and harm with their effects on natality and mortality (II-Q3); in questions II-Q1, Q2 and Q3 the students were asked to write *correct* / *incorrect* in blank spaces; (d) to identify the effects of predation (II-Q4) by writing *increases* / *decreases* in blank spaces; (e) to identify the effects of commensalism (II-Q5); (f) to identify the effects of amensalism (II-Q6); (g) to solve a problem involving a combination of predation and commensalism (II-Q7); in questions II-Q5, Q6 and Q7 the students were asked to write *increases* / *does not change* / *decreases* in blank spaces; (h) to predict the consequences of changes in a population in a food chain with 4 organisms by writing *increases* / *decreases* in blank spaces (II-Q8); (i) to write an essay about the consequences of changes in a food web with 15 organisms consisting of three food chains with 4, 5 and 6 organisms (II-Q9) (see Figure 2).

Questions II-Q1 to Q8 included 34 items for the students to answer. Question II-Q3 was stated using the following format: *Imagine that population X harms population Y. WHEN population X increases, natality of population Y decreases*. Questions II-Q4 to II-Q8 were formulated as *Imagine that population X is the predator and population Y is the prey. IF population X increases, THEN population Y decreases*. In the written essay (II-Q9) the students were asked to explore three kinds of formulations: the same as used in Test I and *Y happens BECAUSE X had happened*.

3.4 Comparing Tests I and II

This experiment was not designed to assess learning based on pre-test and post-test results. Although exploring the same concepts, Test II was far more complex than Test I in many aspects: it explores qualitative models and simulations; it relates natality and mortality respectively to benefit and harm; the effects of the interactions are represented as changes in magnitudes and derivatives of quantities; terms such as X,Y sometimes replace the name of organisms involved in the interactions; it includes a completely new situation, in which predation and commensalism are combined; it provides a more complex food web as motivation, and asked for the students to use three alternative representations of causality in the essay.

Evaluation of the written essays consisted of identifying the manipulation of the concepts, in terms of the types of conclusions drawn by the students in the essays. Following [Sperber and Wilson, 1995], the conclusions were classified as trivial and non-trivial. Details are provided below.

In order to test the significance of the results under the set of hypotheses presented in section 2, three nonparametric statistical tests were used: Mann-Whitney, Chi-square (χ^2) [Siegel, 1975] and the test of significance for proportions in two samples [Stevenson, 1981]. The level of significance was defined in $\alpha = 0{,}05$.

4 Results and discussion

The results obtained in Test I are the following: I-Q1 = [1/3; 2/3; 1/3; 3/3; 2/3; 2/3]; I-Q2 = [2/3; 1/3; 2/3; 3/3; 2/3; 1/3]; I-Q3 = [2/2; 1/2; 2/2; 2/2; 1/2; 0/2]; I-Q4 = [1/6; 1/6; 1/6; 5/6; 1/6; 4/6]; I-Q5 = [2/6; 4/6; 3/6; 6/6; 5/6; 4/6]; I-Q6 = [7/10; 5/10; 5/10; 10/10; 6/10; 5/10].

The results obtained in Test II are the following: II-Q1 = [5/5; 4/5; 4/5; 5/5; 3/5; 5/5; 5/5; 3/5; 5/5]; II-Q2 = [2/3; 1/3; 3/3; 3/3; 3/3; 1/3; 3/3;1/3; 3/3]; II-Q3 = [2/5; 2/5; 2/5; 4/5; 1/5; 3/5; 3/5; 3/5; 5/5]; II-Q4 = [4/6; 4/6; 4/6; 3/6; 4/6; 6/6; 5/6; 5/6; 6/6]; II-Q5 = [1/2; 0/2; 1/2; 1/2; 0/2; 2/2; 0/2; 1/2; 2/2]; II-Q6 = [1/4; 0/4; 4/4; 2/4; 4/4; 2/4; 3/4; 3/4; 3/4]; II-Q7 = [3/5; 3/5; 4/5; 3/5; 4/5; 4/5; 2/5; 1/5; 4/5]; II-Q8 = [2/4; 2/4; 2/4; 4/4; 2/4; 4/4; 1/4; 3/4; 4/4]

The statistical analyses of these scores using the three tests (Mann-Whitney, proportions and χ^2) produced similar results in all the comparisons we made. For the sake of simplicity, only the results of the χ^2 tests are presented here. The research questions discussed here (RQ1-7) are presented in section 2.

The use of qualitative models had a positive effect on the students's capacity of answering objective questions about interactions between populations (RQ1). The global analysis showed that the students gave significantly more correct answers in Test II than in Test I (χ^2 = 4,277; 1 degree of freedom (df); P = 0,039). We believe that the use of qualitative models and simulations made the domain concepts clearer for them, probably because there was a visual representation of the structure of the system involving the two interacting populations, and of the behaviour of the system, shown as a sequence of states, with diagrammatic representations of the values of relevant quantities over time. Information represented this way was easily captured by the students (see answers to questions II-Q1 and II-Q2), a result already found in [Salles *et al.*, 2004].

However, the improvement was not homogeneously distributed among the students. Two out of six students that participate in both tests had significantly better performance and one had significantly worse performance in Test II. In fact, one of the best students (student4) misunderstood some concepts and the teacher and the interpreter were unable to clarify things during the tutoring session. As a consequence, his performance decreased significantly in Test II. The other three students did not show significant improvement in their performance.

Investigating whether or not the students would find more difficult to identify that one population does not affect the other in commensalism and amensalism (RQ2), we found no significant differences in the results of Test I and Test II with respect to commensalism. However, in amensalism the students gave significantly more correct answers to questions involving utterances such as [A causes change on B] than to utterances such as [B does not cause changes on A] (χ^2 = 4,208; 1 df; P = 0,040).

In predation, the students gave significantly more correct answers to questions involving utterances of the type [if the predator is increasing then the prey is decreasing] than to questions involving utterances such as [if the prey is decreasing then the predator is decreasing] (RQ3). These results were observed both within Test I (χ^2 = 8,853; 1 df; P = 0,003) and within Test II (χ^2 = 11,815; 1 df; P = 0,001). However, we found no significant differences between Test I and Test II when comparing correct answers to questions about both types of situations.

Interesting to note that the results reported above about commensalism, amensalism and predation (RQ2 and RQ3) are not related to the students' abilities of recognizing benefit (positive influences) and harm (negative influences) in the three types of interactions (RQ4). The statistical analysis proposed in RQ2 showed no significant differences. A possible explanation for this difference may be the fact that the examples of commensalism explored in the two sessions are found in any textbook and are typically presented by the teachers, while amensalism is not a well known interaction, and the students were not familiar with the examples used to illustrate such relation.

In predation, in which causality is bidirectional, the starting point of the changes may produce very different results. For example, if the predator increases first, then the prey decreases, and if the prey decreases first, then the predator also decreases. Our study showed clearly that the students find more difficulties to identify changes in predator caused by changes in the prey. Maybe it has to do with their knowledge of the world. After all, young children soon notice that predators kill and eat their prey. Realizing that availability of food may cause effects in predator populations is more subtle. However, this is certainly an interesting point for further explore the potential of qualitative models.

Also, we found no statistical support to the hypothesis that it is more difficult to predict propagation of changes to organisms placed two or more levels above or below than changes in organisms at the next level in a food chain (RQ5). It contradicts the results obtained in [Salles *et al.*, 2004], in which the students found more difficulties to find the consequences of changes in the third position (Z) of the causal chain in utterances like [if X is increasing, then Y is increasing and Z is decreasing]. Once again, the better performance here may be related to their familiarity with predation and food chains.

We found no significant differences within Test I and within Test II with respect to the way the organisms involved in the interactions were identified, either by their names or by general terms such as X and Y (RQ6). However, in Test II the students gave significantly more correct answers to questions in which the organisms were identified by general terms (for example, X,Y) than in similar questions of Test I (χ^2 = 10,087; 1 df; P = 0,001). These results suggest that the students' capacity of dealing with abstract representations of populations may have increased after the use of qualitative models, an issue to be explored in further work.

4.2 Linguistic analysis of the written essays

The linguistic performance of the students in the essays was discussed in terms of the notion of relevance, as formulated in [Sperber and Wilson, 1995]. As mentioned above, information that modifies and improves an overall representation of the world is considered to be relevant information. A representation of the world may in turn be regarded as a stock of factual assumptions and each newly acquired factual assumption is combined with the stock of existing assumptions to undergo inference processes whose aim is to modify and improve the individual's overall representation of the world. Factual assumptions consist of representations stored in the memory and treated by the mind as true descriptions of the world. They are acquired from four sources: perception, linguistic decoding, assumptions and deductions.

An assumption is a structured set of concepts to whose presence and structural arrangements deductive rules are sensitive. Concepts appear as an address in memory and may appear as a constituent of a logical form: "when the address of a certain concept appears in a logical form being processed, access is given to the various types of information stored in memory at that address" (cf. [Sperber and Wilson, 1995], p.86). The system monitors for redundancies and contradictions in its derivations, and the device continues to operate until no new theses can be derived.

The improvements in the representation of the world are then traced via the workings of the human deductive device, which takes into account the semantic properties that are reflected in the form of assumptions. For the authors, the human deductive device has access only to elimination rules and yields only non-trivial conclusions. While introduction rules[3] produce trivial conclusions in the sense that "they leave the content of their input assumptions unchanged (except for the addition of arbitrary material)", elimination rules[4] are genuinely interpretive, in the sense that "the output assumptions explicate or analyse the content of the input assumptions (cf. [Sperber and Wilson, 1995], p. 97)."

A central function of the deductive device is to derive the contextual implications of any newly presented information in a context of old information [Sperber and Wilson, 1995]. Non-trivial conclusions are then directly derived, although the validity of arguments may be checked by procedures other than direct derivation. The deductive device is then expected to be complemented with some non-deductive procedures.

When presented with a set of assumptions, the deductive device should directly and automatically compute the full set of non-trivial implications. Trivial implications in turn are not directly computed, being less natural, and subject to different types of mistakes. Once an assumption is submitted to the deductive device, all the deductive rules in the logical entries of its constitutive concepts are accessed. These rules may be analytic and synthetic depending on whether a single or two separate assumptions are taken as input, respectively. Every assumption analytically implies itself, while a synthetic implication is the result of a derivation in which at least one synthetic rule has applied.

Looking at the linguistic performance of the students in the essays, our research question (RQ7) is whether the information in the tutorial supported by qualitative models was relevant, bringing about modification and improvement in their representation of the world (on the interactions between populations). We take the presence of trivial conclusions in the essays to indicate the absence of modification in the representation of the world. Conversely, the presence of non-trivial conclusions, either analytic or synthetic, should indicate that the information to which the student was exposed was relevant. From the students' essays, we selected some examples to illustrate trivial and non-trivial conclusions, shown in (1) to (4), and in (5) to (8), respectively:

(1) "Hawk eats bird."
(2) "Bird eats spider."
(3) "If man dies, man decrease."
(4) "If hawk is the predator of the bird, the bird is the prey of the hawk."
(5) "Given that the owl population decreased, then the rats increase."
(6) "The aphid population increases because the population of ladybug decreases".
(7) "If spider does not eat ladybug, then bird and hawk decrease."
(8) "If the otter decreases, then fish population increases and alligator and man decrease."

---

[3] Exemplifying an introduction rule, the authors say that no speaker would utter (i) expecting a conclusion such as (iia), among others, to be drawn on the basis of this utterance alone:
(i) The Prime Minister has resigned
(ii) a. The Prime Minister has resigned and the Prime Minister has resigned.

[4] Elimination rules are illustrated by *modus ponens* rule:
(i) input: (i) P
(ii) If P then Q
(iii) output: Q

Notice that in (1) and (2) the utterance merely describes a relation between the participants in the food web. We take this description to be old information – which could have been conceptually represented either by means of (previous) formal education or in the course of (informal) everyday life, being part of their knowledge of the world[5]. In (3) and (4), the utterance is an assumption that is rephrased, hence no new information is added.

Differently, in (5) to (8), the utterance refers to causal relations between the populations, further representing the dynamics of the food web – the new information that was taught in the tutorial. The manipulation of the causal relation is considered a non-trivial conclusion, which explicates and analyses the content of the input assumptions.

Statistical analyses of these written essays show a highly significant reduction in the amount trivial conclusions in the essay produced in Test II, as opposed to the one in the Test I (Mann-Whitney test, $n_1 = 6$; $n_2 = 8$; $U = 7$; $P = 0,01$). However, the analyses showed no significant increase in the amount of non-trivial conclusions.

Other linguistic aspects are worth to be mentioned here. The essays produced in Test II showed that the students clearly used more elaborated formulations in the linguistic description of the relations between organisms involved in the food web. For example, embedded utterances such as "If the fish population increases, the algae decreases, (but) increases too the otter, alligator and man populations" were more frequent in Test II.

Another interesting aspect is the observation that when representing the interaction between predator and prey in written texts, a number of important linguistic questions arise. This interaction involves a bidirectional flow of causality, and the propagation of changes may lead to different results, depending on the starting point [if the predator increases, then prey decreases; and if the prey decreases, then the predator decreases]. The students used a number of different strategies to represent these relations. Among them, some explored verbal tense to define the initial point of the causal flow e.g. [if the predator population decreases, then (it may happen because) the prey population has decreased]. Investigating the mastering of tense on the verbs in (written) Portuguese by deaf students is certainly an interesting topic for future research, given the availability of this encoding in LIBRAS.

Some limitations of this study also should be mentioned here. First, the group of students is not representative of the situation of deaf students in Brazilian schools, because very few of them reach the 2nd year in secondary schools. More studies are required in order to generalize the results observed here. Didactic material in experiments like the one described here deserve more attention. For example, we could have used pictures of animals and plants for the students to identify the organisms. Given that deaf students are visual – oriented, figures could improve their understanding of the interactions. We noticed also how important is to make careful use of arrows to represent the relations. For example, to express predation, two arrows were used with positive and negative to identify predator and prey (A ⇆ B) and, in a food web, the same interaction would be expressed by one arrow (B → A) that indicates the flow of energy. These different representations, although usual in biology textbooks and classes, may be confusing for the students.

5 Conclusions

Making inferences is one of the most important human skills for understanding the world. The study described here showed that the use of qualitative models significantly increased deaf students' ability to make inferences about changes in interacting populations. These positive effects were found both in the objective questions and in the written essays the students produced after two tutorial sessions. The students gave, in total, more correct answers to objective questions in Test II than in Test I. An interesting observation was that it is more difficult for the students to recognize propagation of the effects of changes in predators to the prey populations than the contrary. The same difficulty was observed in the written texts, and represents an open issue to be investigated. The study also showed the information in the tutorial supported by qualitative models was relevant, bringing about modification and improvement in their representation of the world (on the interactions between populations). This was confirmed by the observation that the students formulated significantly fewer trivial conclusions after the use of qualitative models. Finally, this study reinforce our opinion that qualitative models are useful tools to support the educational development of deaf students and the acquisition of Portuguese as second language.

[5] Interestingly, the students displayed a better performance in describing the relation between the predator towards the prey than that of the prey towards the predator, in both the essay and the objective tests. This result was not quantified in the essays, although it was shown to be significant in the objective tests.

Acknowledgements

We would like to thank the deaf students, their teachers and interpreters of LIBRAS, in particular Margot Latt Marinho and Gisele Morrison. Thanks also to Maria Inez Telles Walter for the support with the statistical analyses. Finally, P.and H. Salles are grateful to CAPES / MEC for the financial support to the research project "Português como segunda língua na educação científica de surdos" (Portuguese as a second language in the scientific education of deaf).

References

[Bouwer and Bredeweg, 2001] Anders Bouwer and Bert Bredeweg. VISIGARP: Graphical representation of qualitative simulation models. In Moore, J.D.; Luckhardt Redfield, G. & Johnson, J.L. (Editors) *Artificial Intelligence in Education: AI-ED in the Wired and Wireless Future*. Amsterdam, IOS Press, pp. 294-305, 2001.

[Bredeweg, 1992] Bert Bredeweg. *Expertise in Qualitative Prediction of Behaviour*. Ph.D. thesis, University of Amsterdam, Amsterdam, The Netherlands, 1992.

[Forbus, 1984] Kenneth D. Forbus. Qualitative process theory. *Artificial Intelligence*, 24:85–168, 1984.

[Matsushima *et al.*,1987] Kazuo Matsushima et al. *Educação Ambiental: Guia do Professor de 1º e 2º Graus*. São Paulo, Secretaria de Estado do Meio Ambiente e Companhia de Tecnologia de Saneamento Ambiental, 1987.

[Odum, 1985] Eugene P. Odum. *Ecologia*. Rio de Janeiro, Discos CBS, 1985. (Translation of *Basic Ecology*, 1983).

[Salles *et al.*, 2003] Paulo Salles; Bert Bredeweg; Symone Araújo and Walter Neto. Qualitative models of interactions between two populations. *AI Communications* 16(4): 291– 308, 2003.

[Salles *et al.*, 2004] Heloisa Lima-Salles; Paulo Salles and Bert Bredeweg. Qualitative Reasoning in the Education of Deaf Students: Scientific Education and Acquisition of Portuguese as a Second Language. *In* de Kleer, J. and Forbus, K. (eds.) *Proceedings of the 18th International Workshop on Qualitative Reasoning (QR04), Evanston, Illinois*¸ 2-4 August, 2004, pp. 97-104.

[Siegel, 1975] Sidney Siegel. *Estatística não-paramétrica para as ciências do comportamento*. São Paulo, Ed. McGraw – Hill do Brasil, 1975. (Translation of *Nonparametric Statistics for the Behavioral Sciences*, published by McGraw – Hill Inc.,1978)

[Sperber and Wilson, 1995] Dan Sperber and Deirdre Wilson. *Relevance: Communication and Cognition*. Oxford (UK) and Cambridge (Mass), Blackwell Publishers Ltd, 1995.

[Stevenson, 1981] William J. Stevenson. *Estatística aplicada à administração*. São Paulo, Ed. Harper & Row do Brasil, 1981. (Translation of *Business Statistics: Concepts and Applications*, published by Harper & Row Publishers Inc., 1978).

[Weld and de Kleer, 1990] Dan Weld and de Kleer. *Readings in Qualitative Reasoning about Physical Systems*. San Mateo, CA, Morgan Kaufmann, 1990.