LaTina – An online system for teaching and learning stock-and-flow thinking skills

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Abstract

This paper continues a line of work that took up previously published stock-and-flow thinking studies and proposed to apply the model of implicit learning to the case. According to this model, novices have to elaborate personal experience by following rules. After previous trials, a set of such rules is proposed together with a group of challenges that allow to apply and to learn them. A conceptual model for representing the rules, the challenges, the learners and their learning itinerary are proposed. Then, the design for an on-line system for publishing and working with challenges and to monitor progresses is introduced. This software system is currently under construction.

Keywords: system thinking skills, tacit knowledge, learning, expertise

Introduction

Stock-and-flow thinking has been found to be a tricky business for most human beings (Booth-Sweeny and Sterman, 2000; Ossimitz, 2002; Kainz and Ossimitz, 2002): in all the cases studied, subjects failed in several vary fundamental tasks involving one stock and one or two flows.

Schaffernicht (2005a) proposed to use Dreyfus and Dreyfus' (1986) approach to skill acquisition, based on a review of Polanyi's model of implicit integration (Polanyi, 1966; Neuweg, 1999): subjects transform themselves from novices into experts over several stages, by experience and reflection. The *novice* is given general and context-free rules to classify situations and determine courses of action. The *advanced novice* has already a stock of personal references and begins to "compile" his or her own directives (less specific than rules in this terminology). The *competent* has advanced in this same direction and starts recognizing situations implicitly. Finally the *expert* not only recognizes what the case is, he also knows what to do. Schaffernicht (2005a suggested a set of rules and an adaptation of Ossimitz's tests in order to try this out.

As reported in Schaffernicht (2005b), following the indicated rules appears to improve the results in the tests; however, the main finding was that instead of having subjects work through the battery of tests and then giving them feedback, assessment and feedback should be offered right after each of the test situations, in order to use each of these experiences for learning.

This empirical intent and its difficulties have given rise to the design of an on-line system that would allow teachers to define and publish tests (or challenges) and while subjects (students) work on them, the system tracks some key variables in order to show the student his or her progress and to show the teacher (and the researcher) how differently defined groups of subjects evolve. This paper presents the design of this system.

The second section introduces the rules and some conceptual considerations for the presentation of "challenges". The third section describes the internal logical structure of the challenges and how the sequence of decisions/actions a subject (user) takes can be tracked. The fourth section introduces some details about the concrete on-line system; it also gives examples of questions that can be asked to this system.

Rules for novices

When a new situation is approached, the first step is to recognize what is a stock and what is a flow amongst the variables. There are two rules that allow doing so:

1. If the variable refers to a quantity that can be measured at a given *point* in time, then it is a *stock*.
2. If the variable refers to a quantity that has moved or changed during a given *period* of time, then it is a *flow*.

In "Industrial dynamics", Forrester (1961) proposed the following test: imagine that you can stop time; the variables that still exist under these conditions are stocks. Clearly, it is the relationship to time that allows to distinguish stocks from flows. The two rules above may thus be seen as an operational reformulation of Forrester's test.

Once the types of variables have been recognized, one or several judgments have to be made in order to respond to each challenge. These judgments are based on the dynamic relationship between the stock and the flow.

In general, there is a set of rules that a novice can follow (Schaffernicht, 2005a, 2005b) and that can be organized into the following phases:

A. Convert graphical into conceptual information about *inflows* and *outflows*
B. Convert *in*- and *outflows* into a *net flow*
C. Convert the *net flow* into the **accumulator's** dynamics
D. Convert *flow* information into information about extreme values of the **accumulator**

There are dependencies between these phases: Each of C. and D. require B. to have been done; B. cannot be done unless A. has been carried out. There is no such relationship between C. and D.

The following general rules specify actions for each of the phases, allowing to correctly appreciate the situation:

<u>A. Convert graphical into conceptual information about *inflows* and *outflows*</u>

1. When the *inflow* line is above the *outflow* line, the *inflow* is greater than the *outflow*
2. When the *inflow* line is above the *outflow* line, the *inflow* is equal to the *outflow*
3. When the *inflow* line is below the *outflow* line, the *inflow* is smaller than the *outflow*

<u>B. Convert *in*- and *outflows* into a *net flow*</u>

4. When the *inflow* is greater than the *outflow*, the *net flow* is positive
5. When the *inflow* is equal to the *outflow*, the *net flow* is zero
6. When the *inflow* is smaller than the *outflow*, the *net flow* is negative

<u>C. Convert the *net flow* into the **accumulator**'s dynamics</u>

7. When the *net flow* is positive and constant, the **accumulator's** level grows linearly; its change is equal to the value of the flow.
8. When the *net flow* is zero, the **accumulator's** level is constant.
9. When the *net flow* is negative and constant, the **accumulator's** level lowers linearly; its change is equal to the value of the *flow*.
10. When the *net flow* is positive and grows constantly, the **accumulator's** level grows exponentially; its change is equal to the value of the *flow* during each distinguished period.
11. When the *net flow* is negative and lowers constantly, the **accumulator's** level lowers exponentially; its change is equal to the value of the *flow* during each distinguished period.

<u>Convert *flow* information into information about extreme values of the **accumulator**</u>

12. When the *net flow* changes from positive to negative, the **accumulator's** level is at a local maximum.
13. When the *net flow* changes from negative to positive, the **accumulator's** level is at a local minimum.

<u>Continuity of the **accumulator**</u>

14. A accumulator's level at the beginning of a period of time is equal to its level at the previous period's end.

Phases A and B point to very rudimentary actions that may appear not to need explicit rules to be carried out properly. However, already Ossimitz (2002) remarked that graph reading skills may be a challenge apart. In the authors experience with Chilean undergraduate business students, reading graphs and properly converting in- and outflows into a net flow are not a trivial task for many. This justifies the insertion of these rules into the set.

To the trained system dynamicist, the of phase C are simply consequences of the mathematical relationship between stocks and flows. However, the rules are supposed to recall to the novice what the practical consequences of this relationship are. With some little transformations, we can move from the rules to integration/derivation.

Rules 7-11 can be reformulated in a slightly more abstract form: "The stock's level changes by the amount the flow differs from zero". This is a non-mathematical way to say that the stock integrates the flow's values from the different periods of time. Rules 6 and 7 are a consequence of the previous rules. Rule 8 always applies and assures that there be no discontinuity. So we may hope that a novice who follows these rules will act as if he applied the mathematical relationship.

However, the challenges are not directly presenting stocks and flows; rather, they describe a situation using one or several forms of representation: text, numbers or graphics. Thus, in order to follow the rules the novice has to interpret the given material in order to discover which of the rules applies. This means that in addition to the general rules discussed here, each challenge has its own specific set of rules that have to be applied in order to correctly apply the general rules.

Let us look at one example: the classical bathtub task (Booth-Sweeny and Sterman, 2000); a more complete description can be found in Schaffernicht (2005b). In this challenge, the situation is described by a graphic representing a flow, and the subjects have to respond by completing the stock part of the graphic.

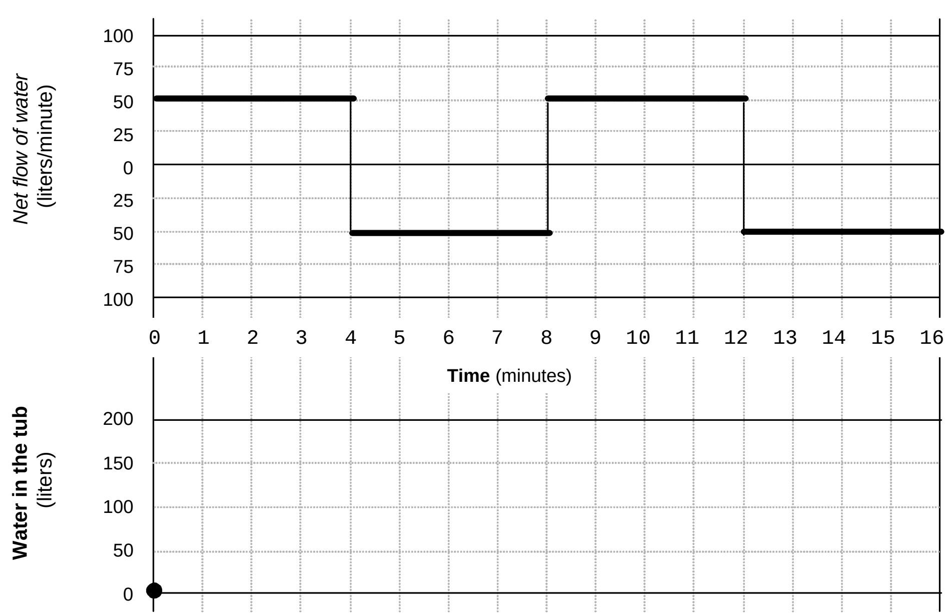

Figure 1: the bathtub situation

As typical for our cultural context, this graphic will be read from left to right. In doing so, several phases with their sets of specific rules are involved.

Phase A, referring to the graphic representation of the situation, we have to apply rules 1 and 3:

a) Rule 1 during minutes 1-4 and 9-12;
b) Rule 3 during minutes5-8 and 13-16.

Phase B is not necessary, for the represented flow is already a net flow.

Phase C: according to this, one identifies rules 7 (for minutes 1-4 and 9-12) and 9 (for minutes 5-8 and 13-16). In drawing tasks, it is not clear as yet if there will be need for specific rules con converting, for instance, "the **accumulator's** level grows linearly" into a descending linear line.

When applying these rules and trying to draw the resulting level, rule 14 has to be taken into account (continuity of the accumulator). When doing so, the level's line is drawn.

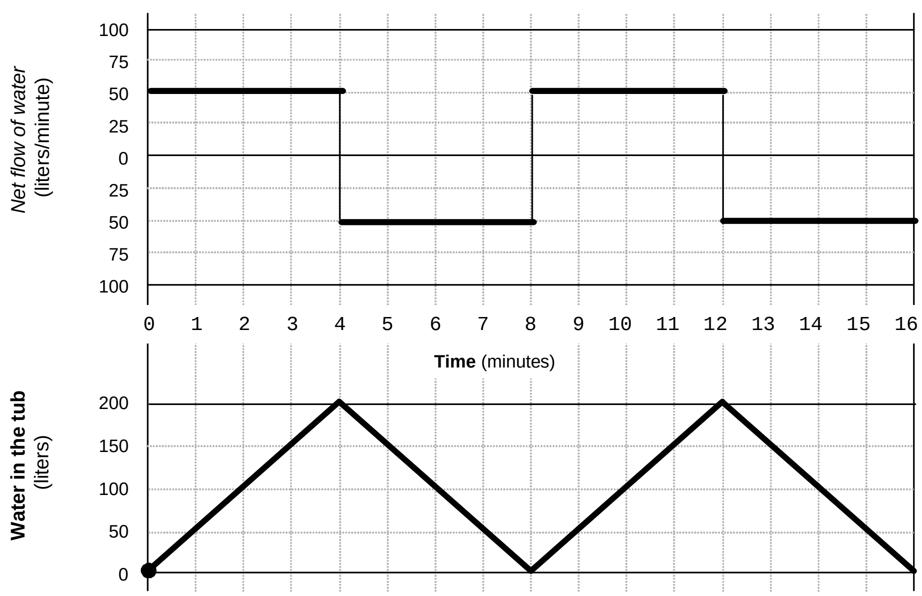

Figure 2 the bathtub situation resolved

Now the subject can visualize that at three points in time rules 12 and 13 apply, since the flow changes between positive and negative values.

Again, this may seem obvious to the trained individual, but we are here working with novices.

As reported in Schaffernicht (2005b), these rules have been woven into the 6 test situations developed by Ossimitz (2002) and tried out on a group of undergraduate business students. In this test students had to respond to the entire series of test situations in one uninterrupted session; for each task, they could chose to use the rules (handed out on a separate sheet) or work without them, and there was no time restriction. Even if the low number of students (8) did not allow to derive conclusions, the students who used the rule sheet clearly outperformed the other ones. No change in performance could be observed over the six tests, which seemed to contradict the idea that repeated application of the rules would trigger learning and becoming independent of these rules.

However, this does not mean that the whole idea has to be rejected. Rather, it seems that this was the consequence of applying the six tasks in one set. In order to learn from action, the consequences have to be evaluated; this means that one task's response should be evaluated before the following task is faced. This recognition lead to a redesign of the tasks that will now be presented.

The structure of a challenge

Depending on one's standpoint, the units like the bathtub task may be called "task", "exercise", "situation" or "experiment". Inside the context of this line of work, the intention behind these units is to make the learners expand their abilities. There appears to be little relation with this intention when the unit is called "task" or "situation" (neutral) and "experiment" (interesting only to the researcher); "exercise" sounds a little boring. So here it is proposed to call these units "challenge": to the learning novice, they are challenging, and hopefully seeing them as challenges mobilizes mental and affective energy.

The idea underlying this work is that novice stock-and-flow thinkers can transform themselves into competent ones by affronting a series of challenges:

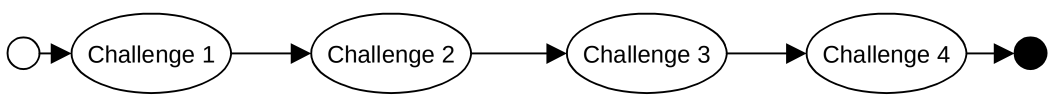

Figure 3: a sequence of challengs triggers learning

At the start (blank oval), there is a novice, and he will work through a series of challenges until we can say he is now a competent stock-and-flow thinker and the process is considered as terminated (the solid oval stands for "end").

Each challenge – like the exemplary one used in the previous section – is decomposed into steps (a sequence of decisions taken by the learner, corresponding to the phases presented in the previous section). There are two types of decisions: selecting the rule to apply and applying it:

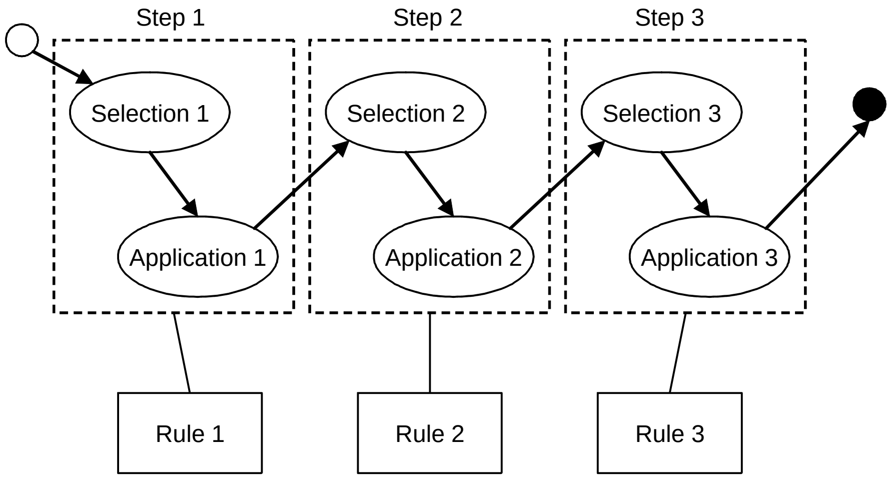

Figure 4: a challenge is a sequence of steps

Each step of a challenge is a manifestation of one of the rules, and the way from "start" to "end" is a sequence of rules to be recognized and applied. Since the rules have been already discussed in the previous section, we now concentrate on the steps:

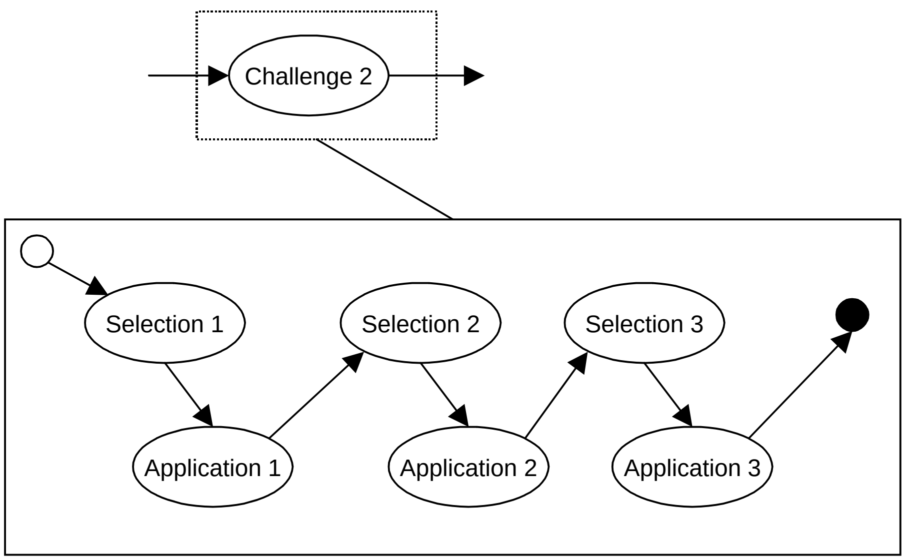

Figure 5: a challenge is a sequence of selecting and applying rules

In the case of the exemplary bathtub challenge, for instance, selection 1 would be to identify rule 2 as the one to be applied; application 1 would be to draw the first segment of the level's line. Of cause, the learner can select the right or the wrong rule and apply it in the correct or a wrong way. Since we want him to learn from his mistakes, there is a correction offered for each different mistake:

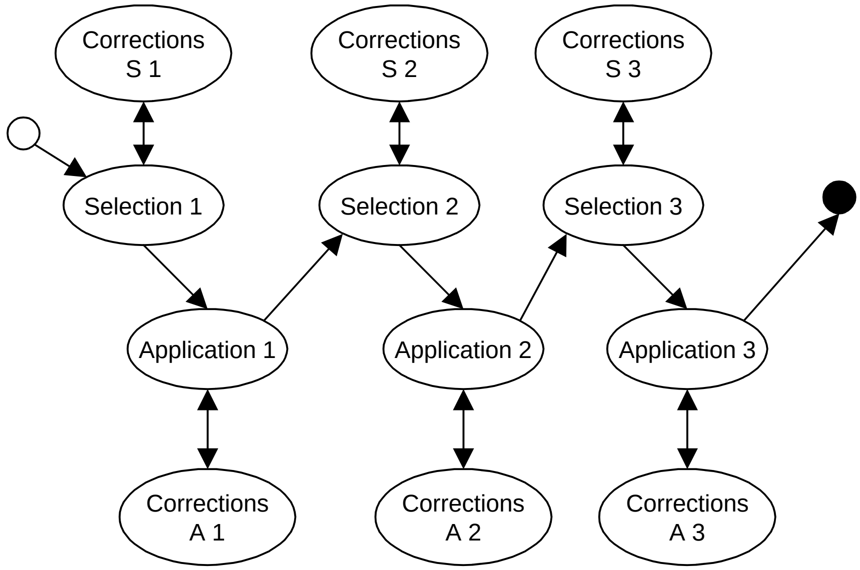

Figure 6: each possible mistake is corrected at each step

This assures that the time between taking a decision and obtaining feedback on it is short, and when reaching the "end", the learner knows that he arrived at the correct response: he met the challenge.

The way of the learner through a challenge is then a sequence of steps, each of them decomposed into selection and application. At each selection or application, the learner makes a certain number of attempts until having it right, and each attempt consumes a certain amount of time. So each decision of each step takes time to be taken correctly. Of cause, the novice will need more time than the competent, and during his learning process, time will tend to become shorter. Inversely, when the time needed to come to a correct decision declines, this means that the individual is learning. This holds at the level of the decisions, the different steps (and rules implied) and the challenges.

So if one monitors a learner over a set of, say, seven challenges, one may discover the trace of learning going on:

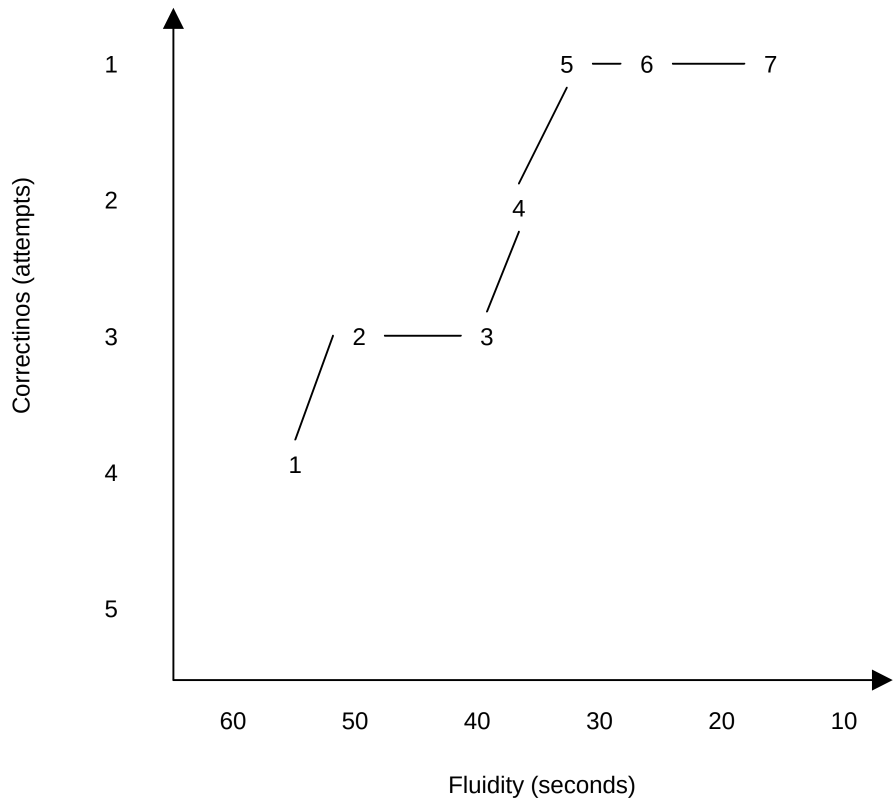

Figure 7: fewer mistakes and fewer time reveal learning progress

In the example shown in Figure 7, the number of attempts taken on the way through the steps declined, as did the time taken per challenge; a closer look reveals that first the number of mistakes declined, then the time needed to carry out the correct decision grew lower. Of cause, this is a hypothetical example and does not pretend to suggest a regularity in the learning paths, even though this way of representing them will hopefully help discovering some (in the future).

A challenge is then a series of steps related to rules, where for each selection and application of a rule there is either a confirmation (getting to the next step) or a correction. The researcher and the teacher need to define challenges and monitor how different subsets of learners do (evolve) in different rules and types of challenges (graphic, textual and numerical representation); the learner wants to work through challenges and see his own progress. All of them can be helped with a tool that captures the attempts and the time taken each time a learner works on a challenge. Such a tool will be now described.

The on-line system

The tool is called "LaTina"; this strange name stems from the fact that it has been invented and is developed in Latin America and that in Spanish, the bathtub is "*la tina*".

The goal of LaTina is to allow to publish and work through challenges and receive progress information.

For learners:

1. select challenges;
2. work through challenges;
3. observe their evolution.

For academics:

1. publish challenges;
2. get information on challenges and rules on different levels of aggregation.

Example of one challenge

The screens have a layout consisting of 5 major regions.

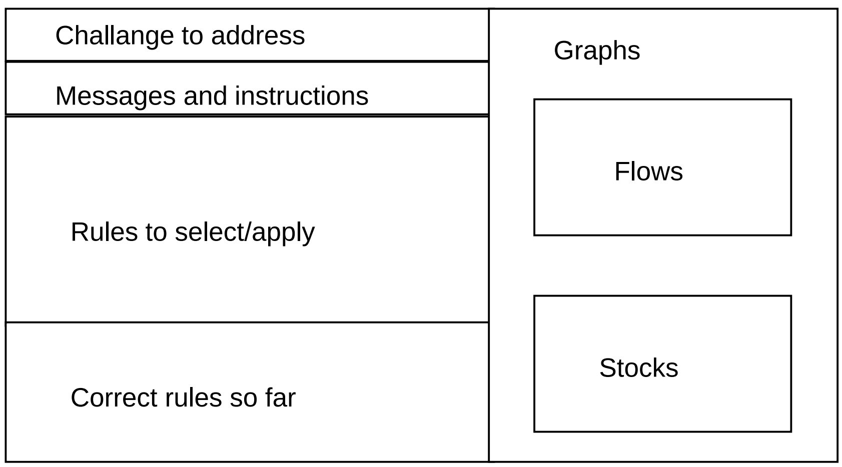

Figure 8

In Challenges to address, the challenge's central question is displayed. The current step's situation is graphically represented in the Graphs region (which develops together with the progress over the steps). In Messages and instructions, the learner sees what is expected from him at the current step, and feedback messages after having made a mistake. In Rules to select/apply, the set of rules that might be correct for the current step. Correct rules so far contains the chain of correct rules of the steps already done.

The following example is taken from the current implementation. One complete challenge is presented in appendix 1.

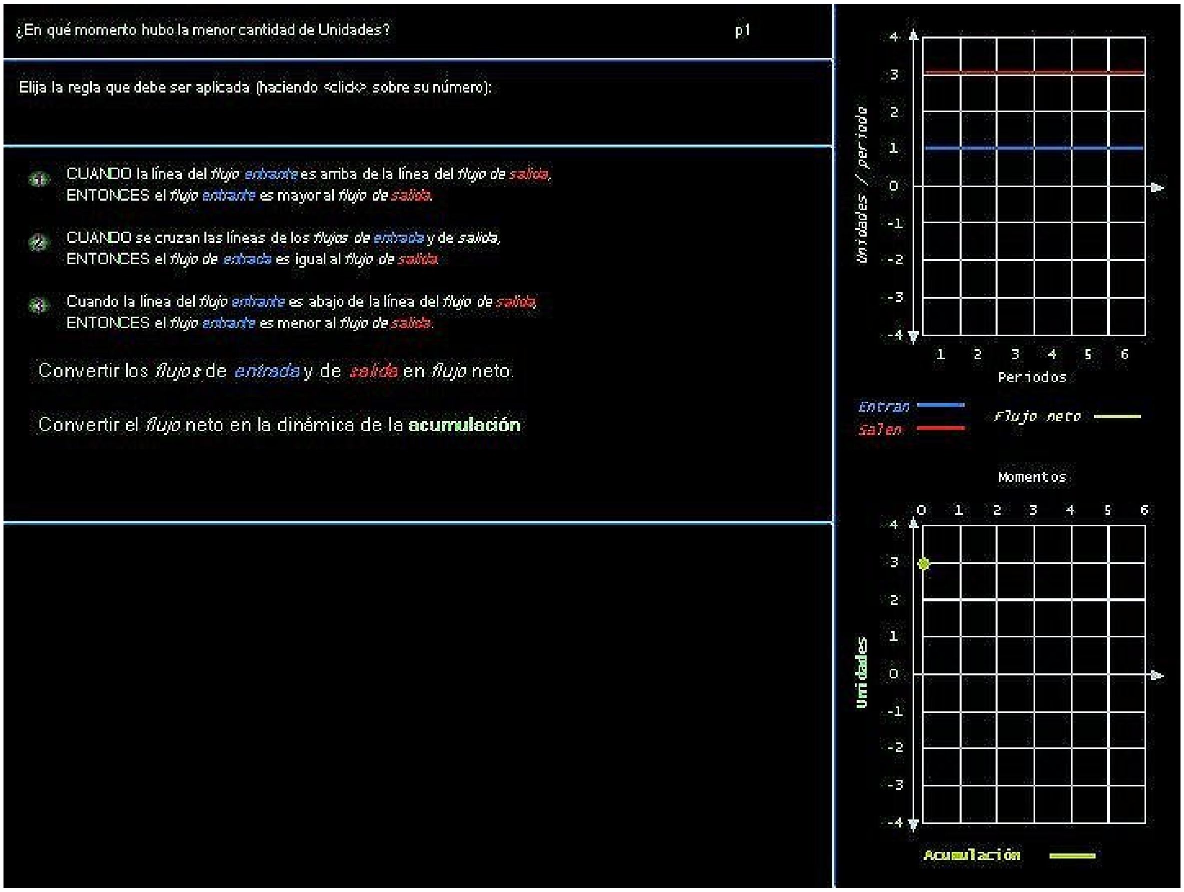

Figure 9: example of a screen

Structure

LaTina's capability to inform about learning progress is grounded in a database containing all relevant data concerning what learners have done. In particular, LaTina has to keep track of how many times the learner attempts to select/apply a rule in one step of a challenge, and how much time this takes him.

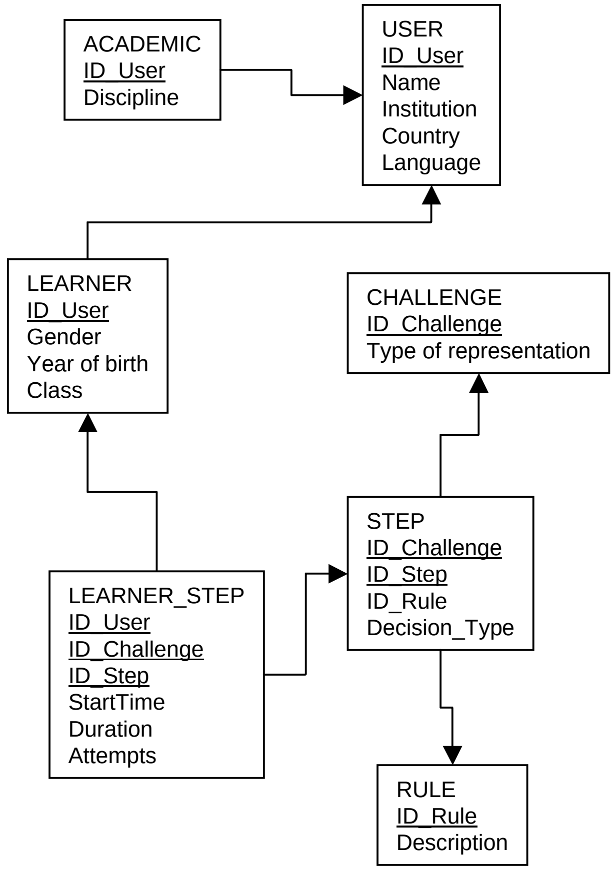

Figure 10: relational data model

In Figure 10, the boxes represent "tables" in the database; a table is a set of attributes that depend on a (set of) key attribute(s). For instance, the "gender" of a "learner" would not have any meaning without identifying the learner; thus the gender is recorded together with the learner.

Between some tables, there are arrows indicating a relationship of dependency: for example, a "challenge" is decomposed into a sequence of "steps". Each step is recorded together with the challenge's key and so the attribute "ID_Challenge" appears in both tables. The fact of storing challenges and steps in separate tables enables us to store challenges with varying numbers of steps. The redundancy of some key attributes allows to re-ensemble the information peaces. For instance, one can ask to identify all the records of "learner-step" that inform about a "step" related to a given "rule", or ask for the set of rules that are implicated in a given challenge.

The database thus designed is robust and versatile. The different procedures of laTina (creating an account, selecting a rule while working through a challenge) deposit the relevant information while the users are realizing their activities.

Questions that can be asked

The learner can ask:

1. How have I done in the challenges that I've worked through so far (in general and for graphical, textual or numerical representation)?
2. How have I evolved concerning the different rules, in general (in general and for graphical, textual or numerical representation)?

These questions' scope is limited to the individual learner.

The academic may define the set of learners to be taken into account, depending on the gender, the age (year of birth), the nationality, the language, the institution and the class. This makes it possible to monitor "my current students" as well as observing "all Spanish speaking women". Inside this set definition, the supported questions are

1. How have they done in the challenges worked through so far (in general and for graphical, textual or numerical representation)?
2. How have they done in the steps worked through so far (in general and for graphical, textual or numerical representation)?
3. How have they evolved concerning the different rules, in general (in general and for graphical, textual or numerical representation)?

Current state

LaTina is currently being implemented using the mySQL database system and PHP for programming the procedures. The choice of these implementation tools is due to the need of providing a tool for the whole system dynamics community: its use by learners and academics is meant to be free of charge and future extensions and modifications may be jointly elaborated.

The system is available at dinamicasistemas.utalca.cl/laTina from Septermber 1st on.

Conclusions

This paper proposed a set of rules that allow a novice to respond to challenges implying the relationship between stock and flow variables. As a means for learning to behave according to these rules, challenges were introduced as a sequence of steps connected to a rule each. Each challenge was designed such as to guide the learner through the steps, correcting his mistakes on the way.

An online information system "laTina" was introduced to publish challenges and to keep track of the quantity of mistakes and of time consumed each time that a learner connects to laTina in order to work through a challenge. LaTina was designed to inform each learner about his personal itinerary and also to inform academics – teachers and researches – about what happens with challenges, steps and rules according the data from different groups of learners.

LaTina is proposed as a medium for the three groups: novices wishing to learn stock-and-flow thinking, teachers wishing to use and publish challenges (in any language that uses the latin alphabet) and researchers wishing to study data on the learning of stock-and-flow thinking.

This is clearly a work "in progress", and hopefully discussion at the conference will improve on it.

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Appendix 1. One exemplary challenge

Step 1

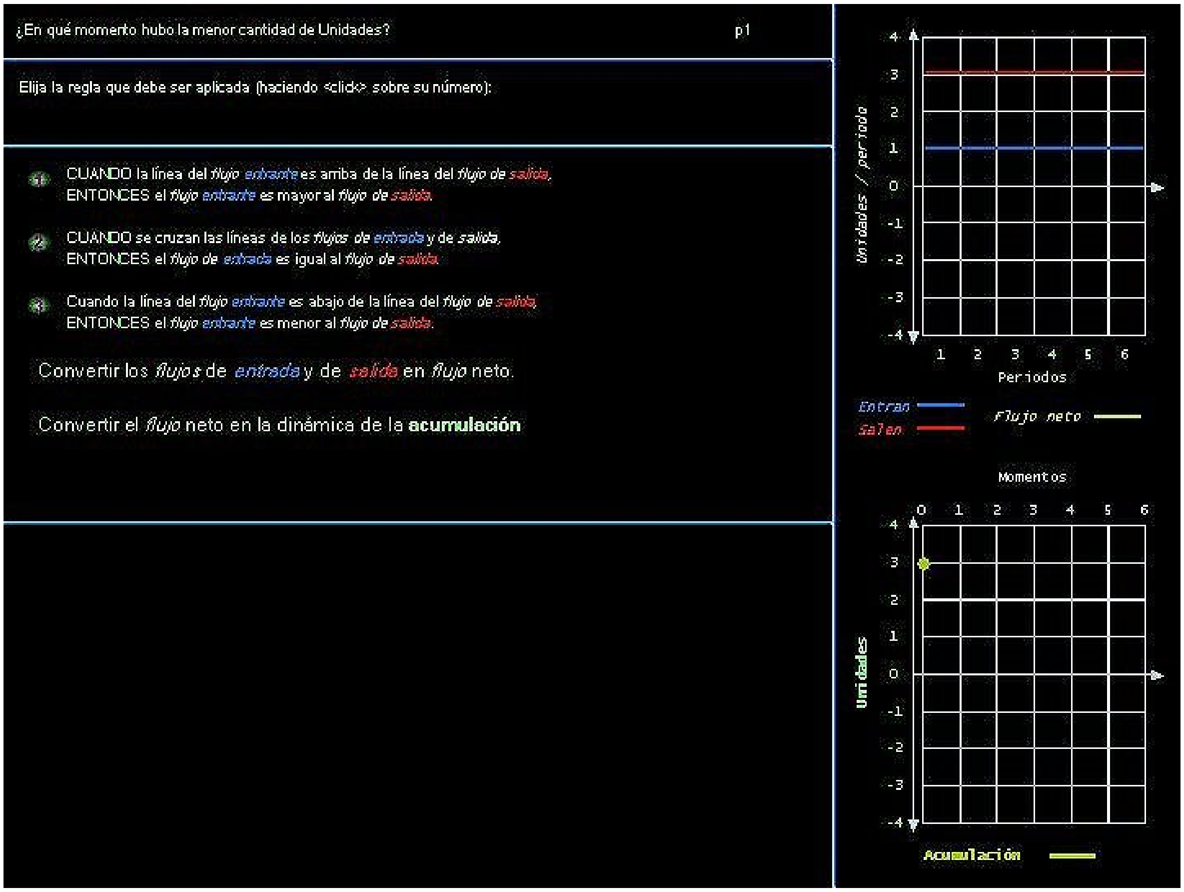

Figure 11 : Step 1

The challenge is presented together with the graphical representation of an inflow and an outflow: in which moment was there the minimum quantity?

The first phase is to convert the graphical information; there are three possible rules, one of which is the correct one, given the red and the blue line representing outflow and inflow. Which is the correct one?

Error 1.1

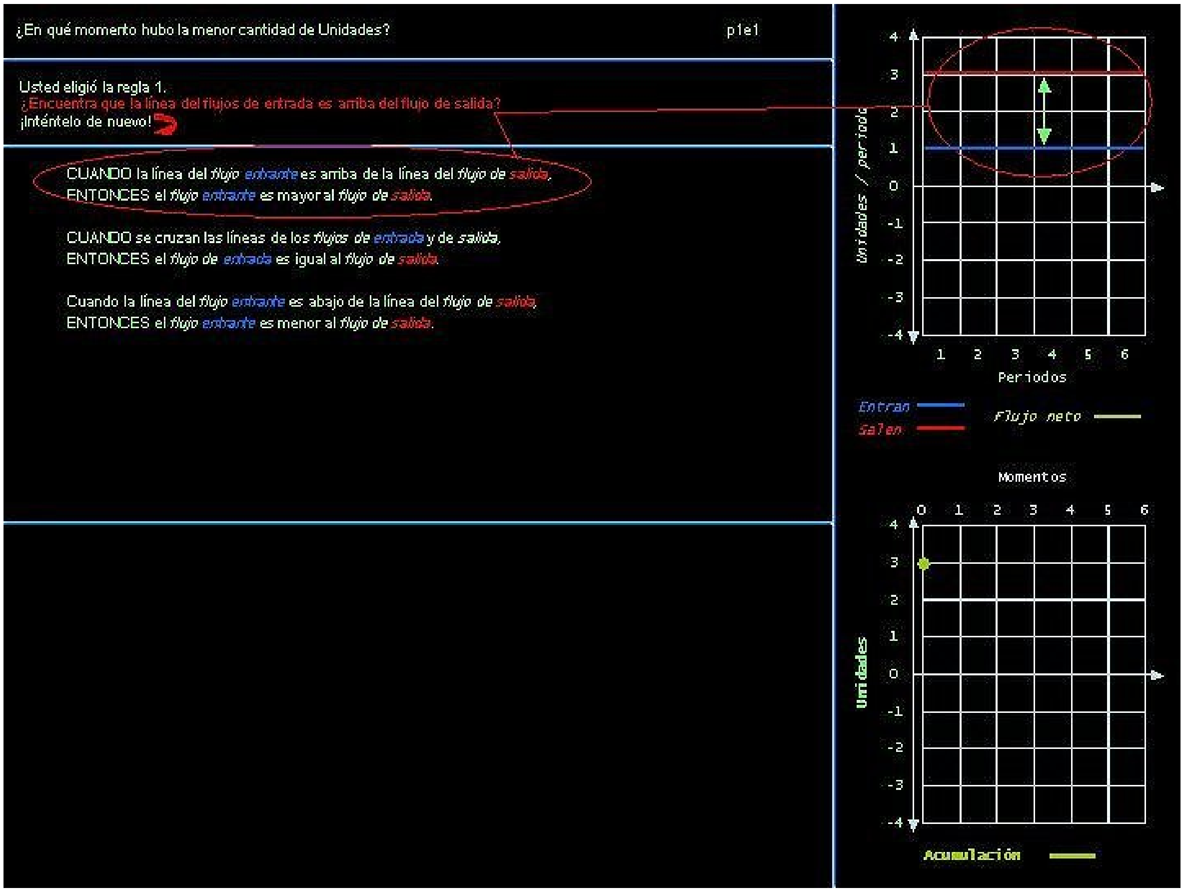

Figure 12: Error 1.1

“You have chosen a rule that refers to <the inflow line is above the outflow line>. Do you think this is a reasonable choice? Try again.”

This error message is meant to orient the learner, who has to return to the previous screen and try again.

Error 1.2

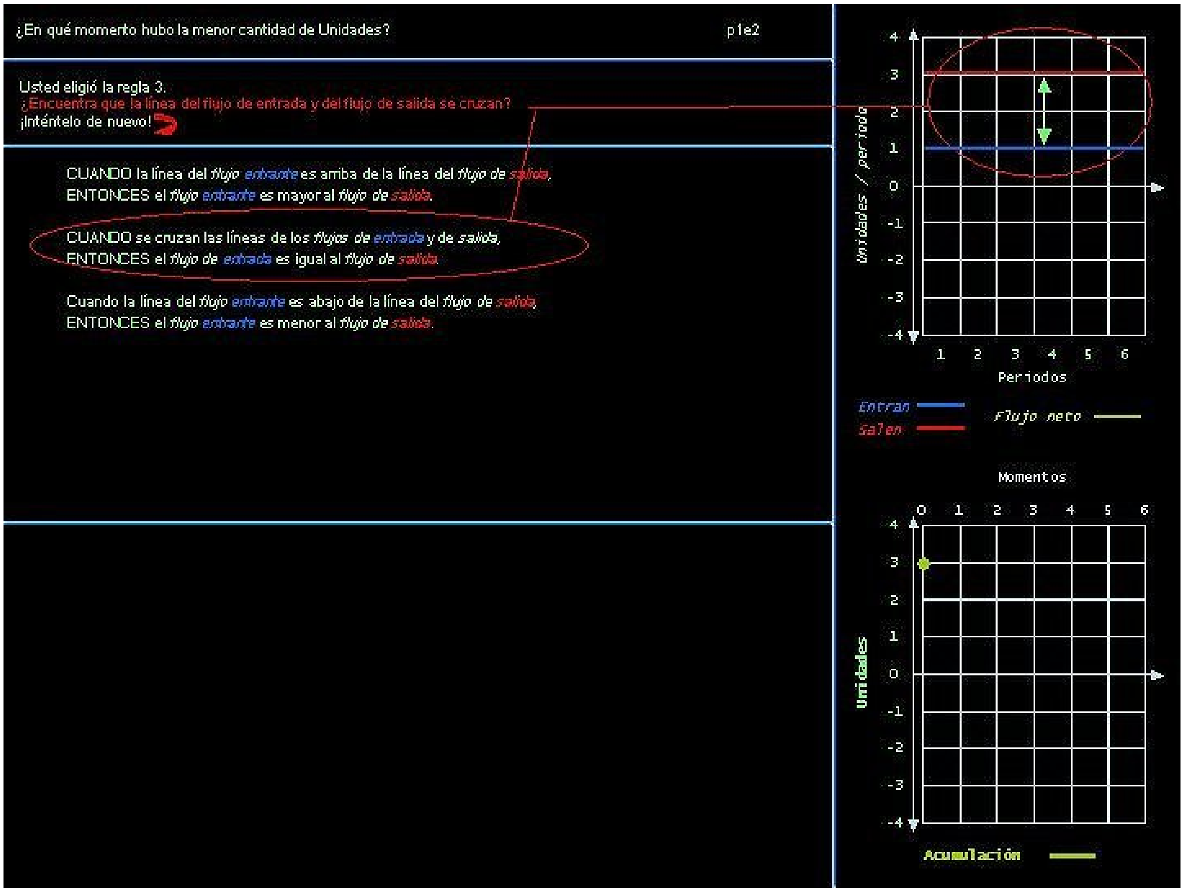

Figure 13: Error 1.2

"You have chosen a rule that refers to <the inflow line crosses the outflow line>. Do you think this is a reasonable choice? Try again."

This error message is meant to orient the learner, who has to return to the previous screen and try again.

Step 2

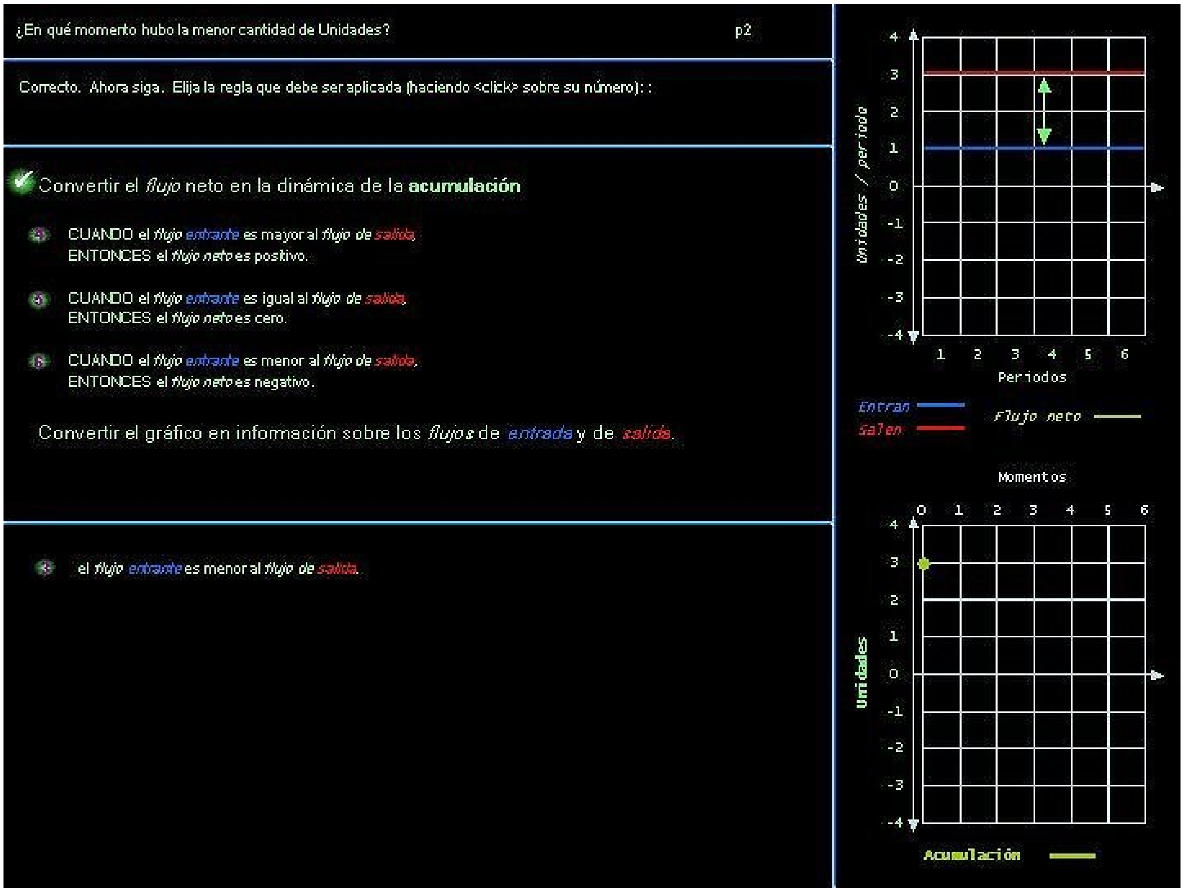

Figure 14: Step 2

The learner has correctly cosen rule 3 (in the case of this challenge). Now he has to FACE the second phase: convert the inflow and the outflow into a net flow. Again, there are three posible rules. Which one is correct now?

Error 2.1

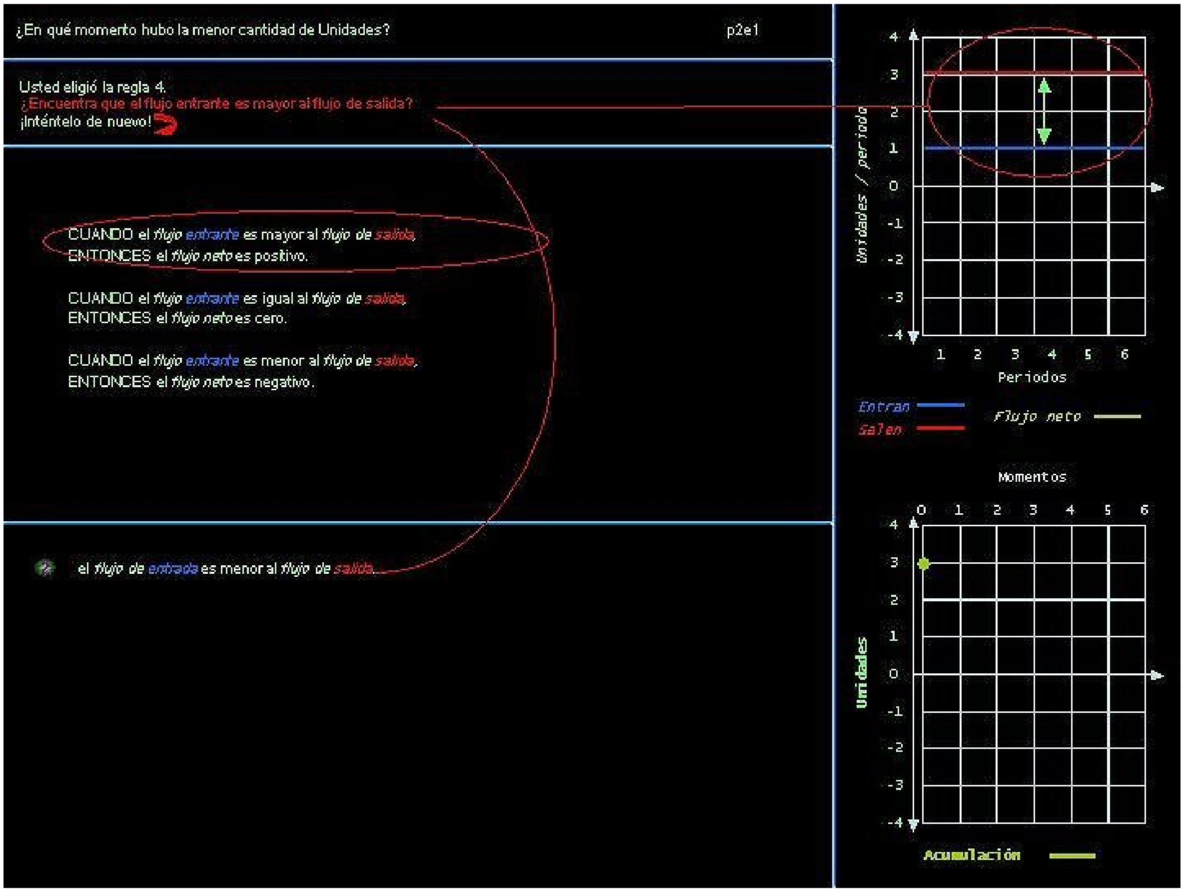

Figure 15: Error 2.1

“You have chosen a rule that refers to <the inflow is greater than the outflow >. Do you think this is a reasonable choice? Try again.”

This error message is meant to orient the learner, who has to return to the previous screen and try again.

Error 2.2

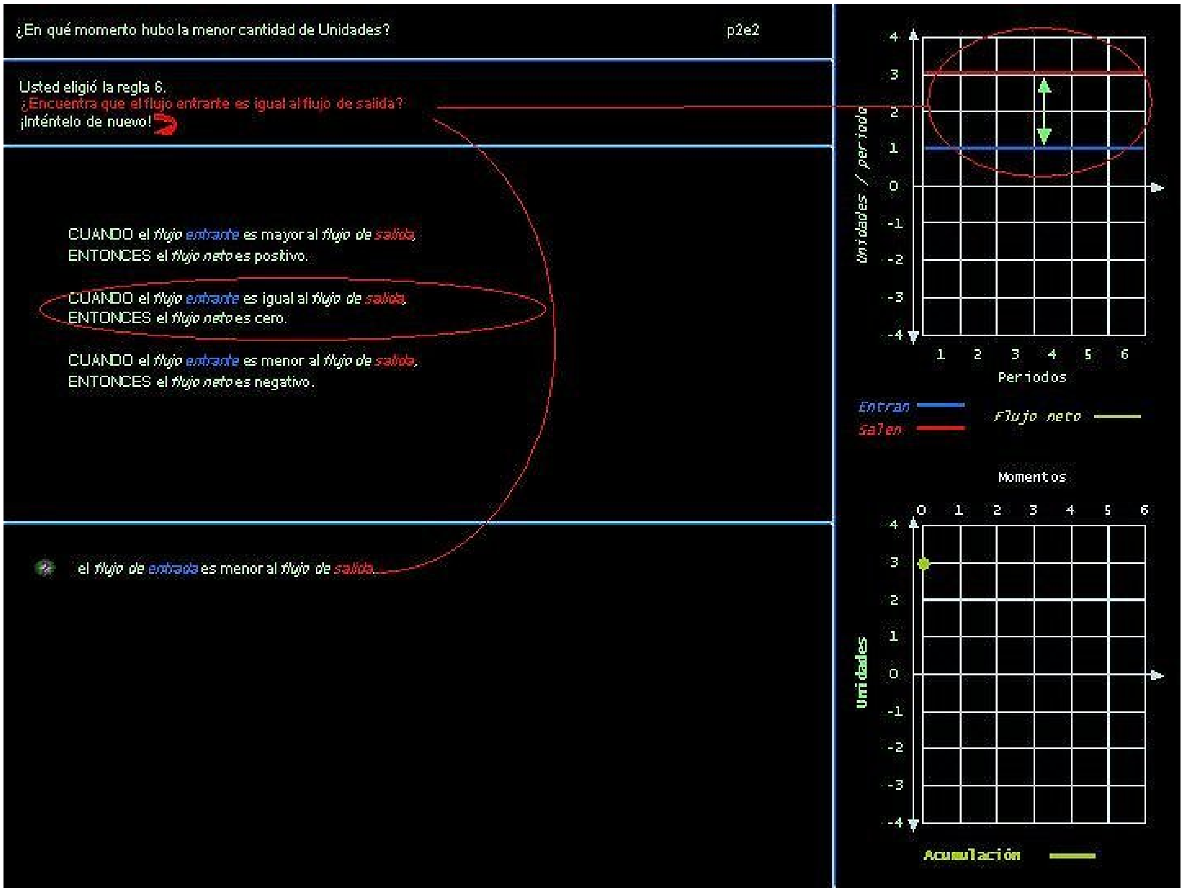

Figure 16: Error 2.2

"You have chosen a rule that refers to <the inflow is equal to the outflow >. Do you think this is a reasonable choice? Try again."

This error message is meant to orient the learner, who has to return to the previous screen and try again.

Step 3

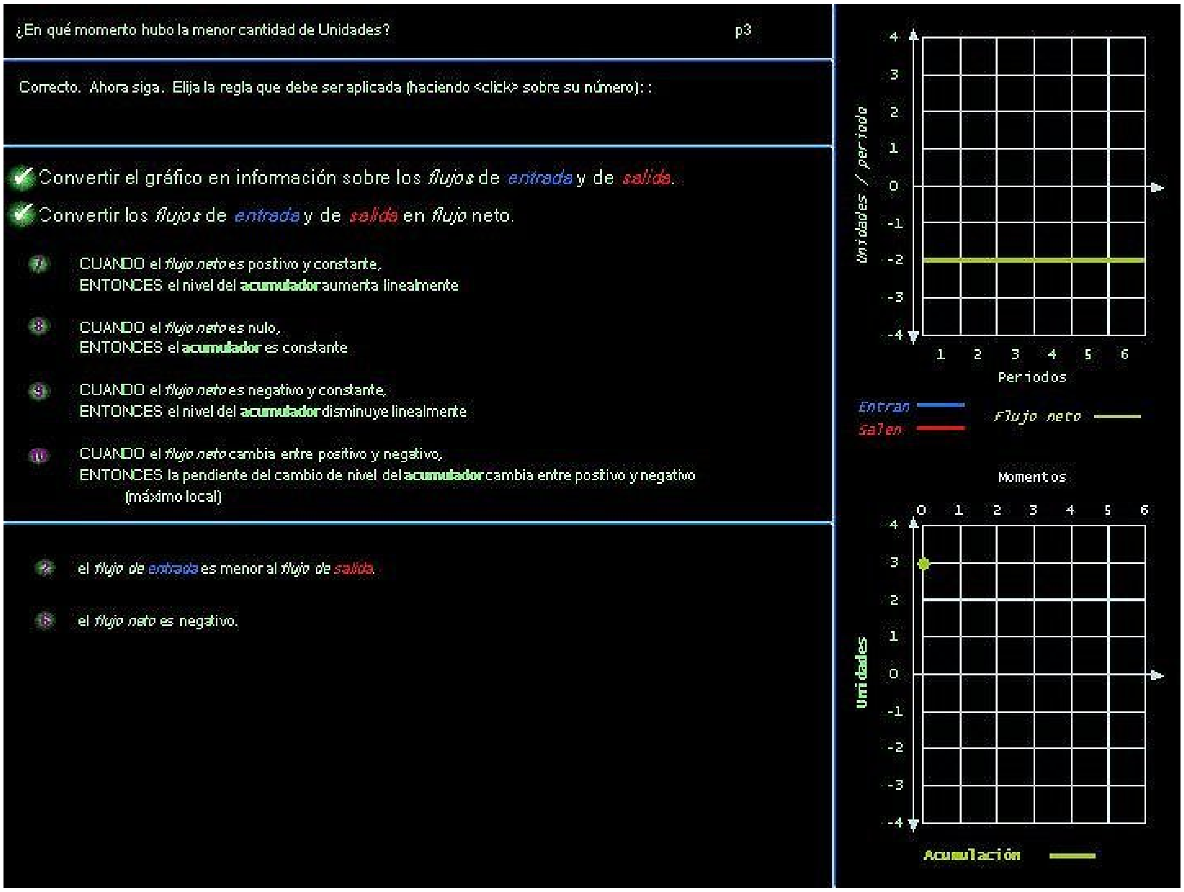

Figure 17: Step 3

The learner has chosen the third of the rules and now he has to convert the net flow into the accumulator’s behavior. There are four rules to choose from.

Error 3.1

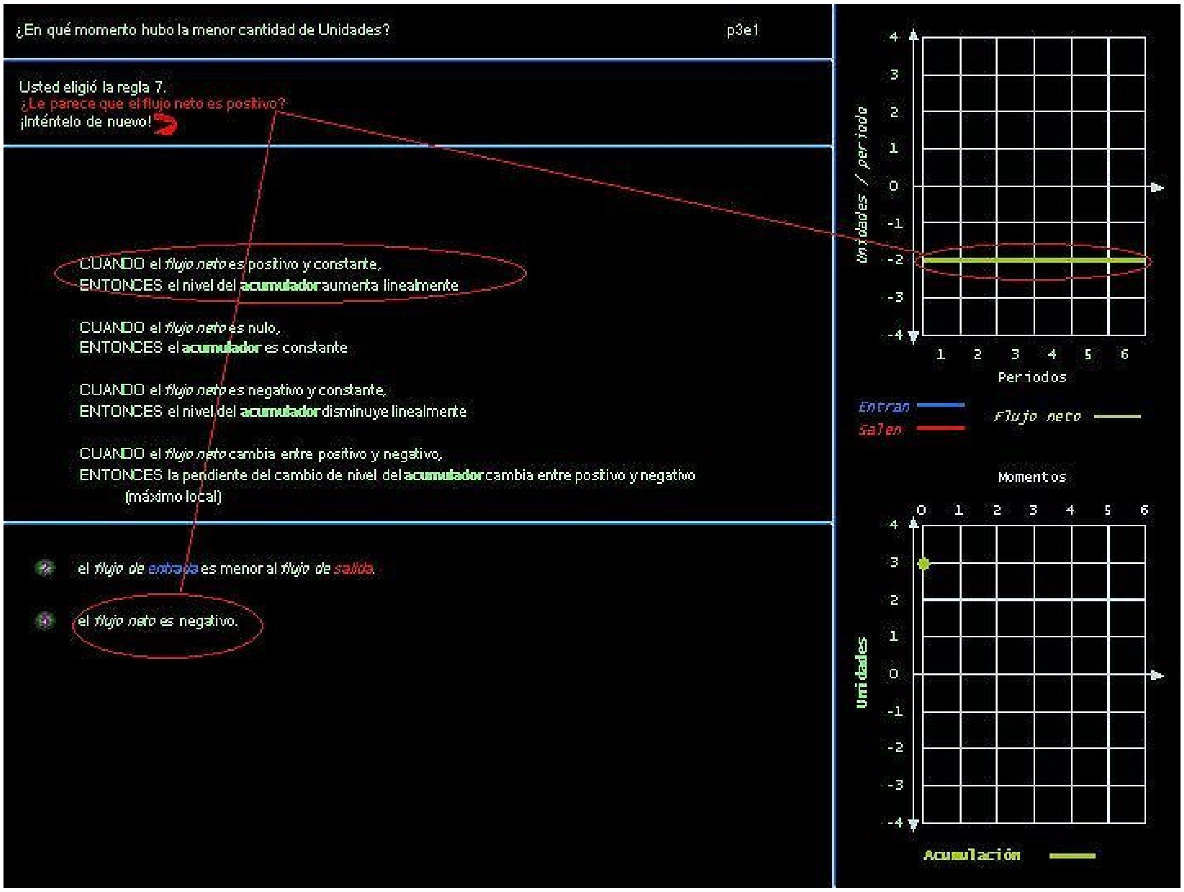

Figure 18: Error 3.1

"You have chosen a rule that refers to <the net flow is positive and constant >. Do you think this is a reasonable choice? Try again."

This error message is meant to orient the learner, who has to return to the previous screen and try again.

Error 3.2

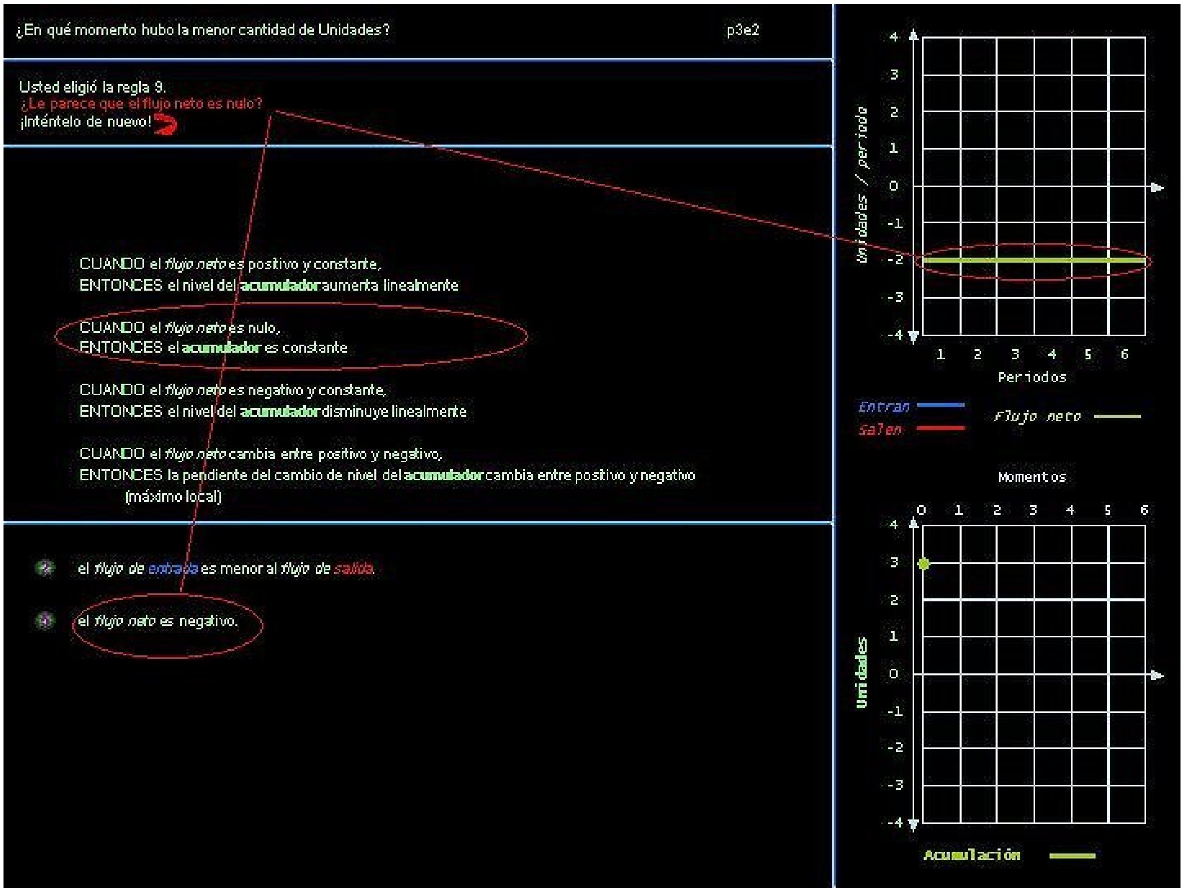

Figure 19: Error 3.2

"You have chosen a rule that refers to <the net flow is cero >. Do you think this is a reasonable choice? Try again."

This error message is meant to orient the learner, who has to return to the previous screen and try again.

Error 3.3

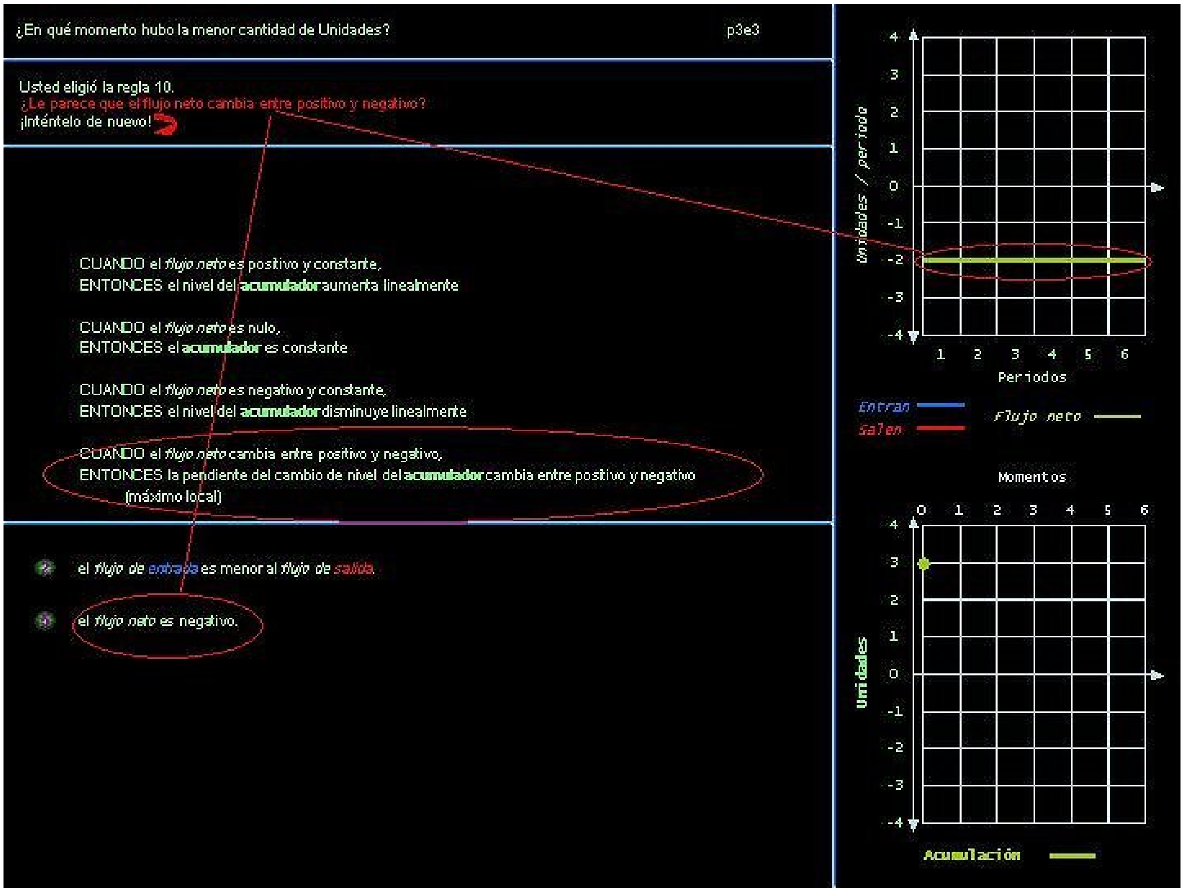

Figure 20: Error 3.3

“You have chosen a rule that refers to <the net flow changes between positive and negative >. Do you think this is a reasonable choice? Try again.”

This error message is meant to orient the learner, who has to return to the previous screen and try again.

Step 4

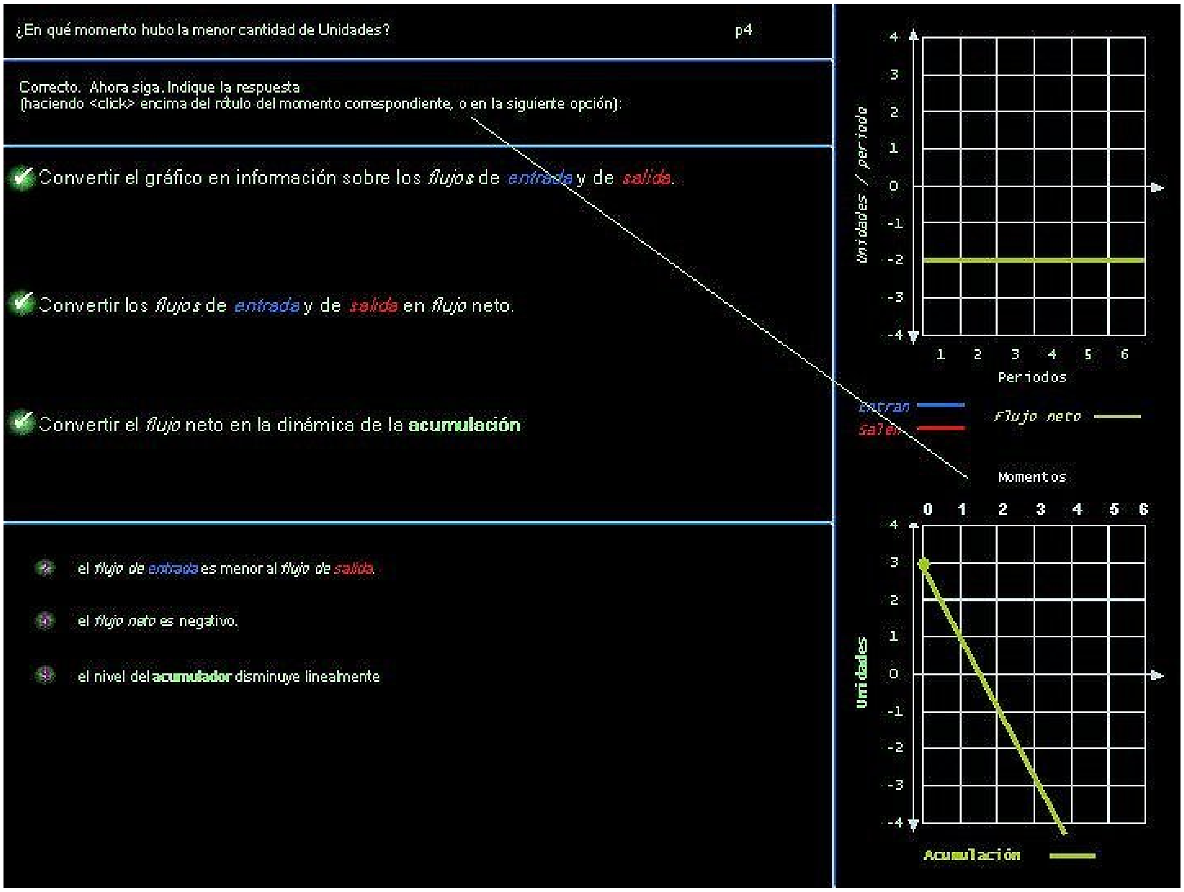

Figure 21: Step 4

The learner has so far chosen that the inflow is smaller than the inflow, that the net flow is negative and that the accumulator diminishes lineally. Now back to the main question: when does the quantity in the accumulator reach its lowest level?

Error 4.1

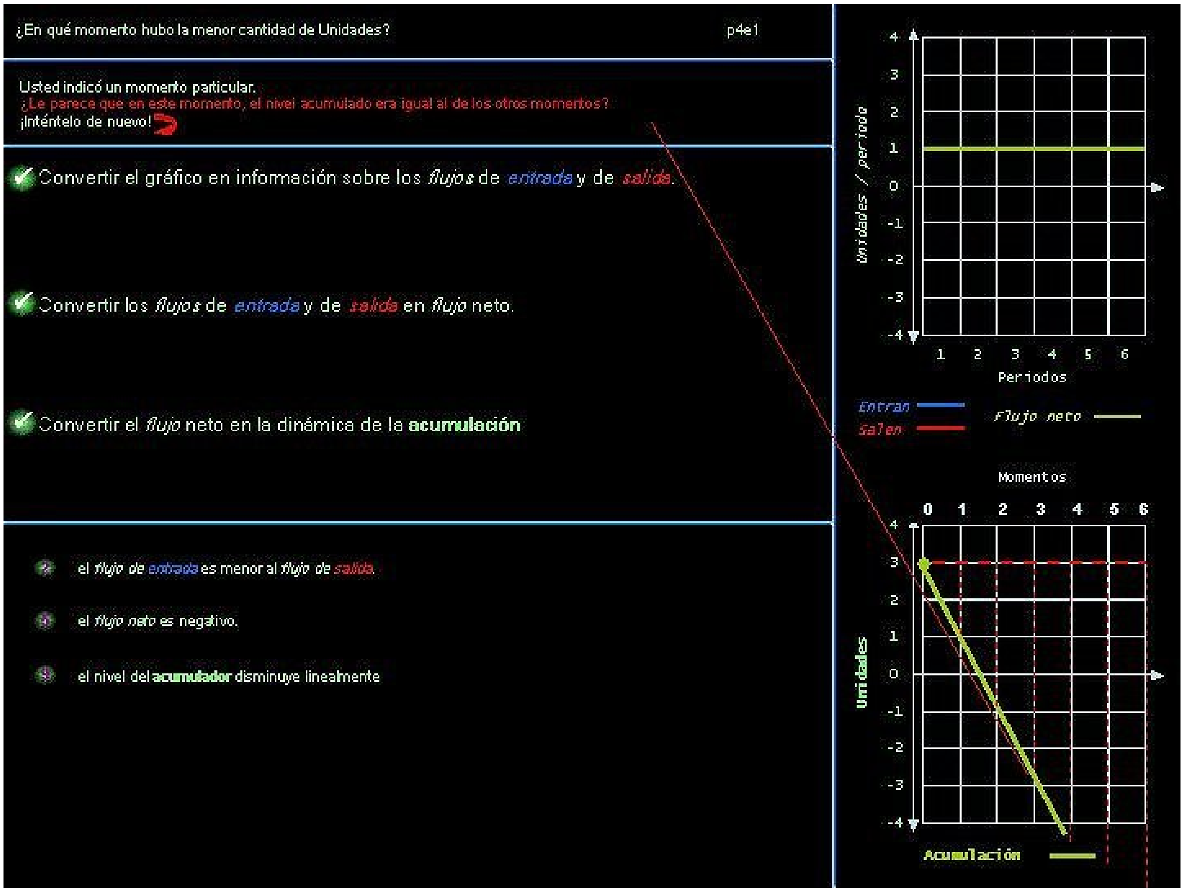

Figure 22: Error 4.1

The learner has clicked on a moment prior to "4": "Do you think this is a reasonable choice? Try again."

This error message is meant to orient the learner, who has to return to the previous screen and try again.

Finish

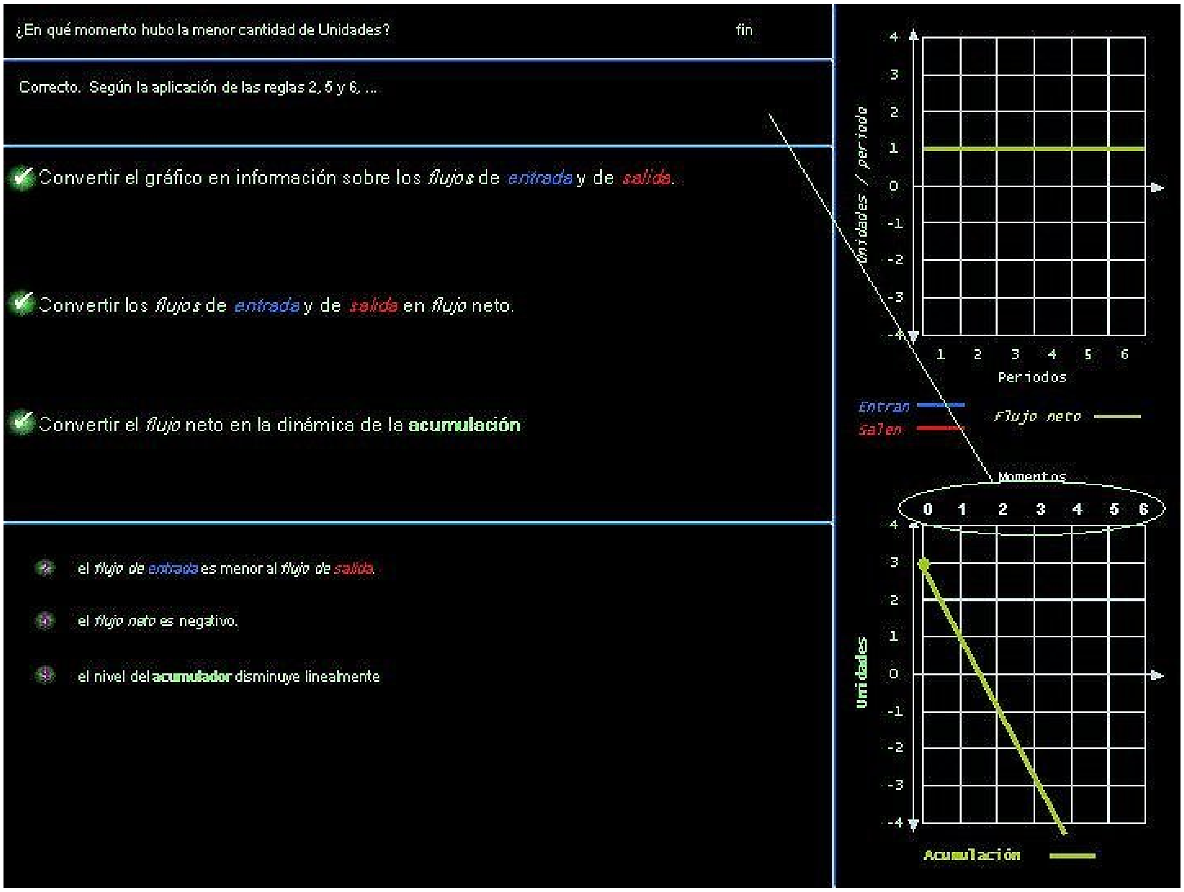

Figure 23: Finish

"Right. According to the rules 2, 5 and 6, the lowest quantity is achieved at moment 4 (the last moment measured)".

Now one can ask how many attemps and how much time the learner has used to reach this conclusion.