Science Learning Object Design: An Experimental Comparison between Instructional Content formats

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ABSTRACT
The Cognitive Theory of Multimedia Learning provides useful principles for Instructional Content Design. Meanwhile there is a lack of evidence about efficacy of these principles with children and adolescents in scholar context. In order to evaluate how the use of infographics, animations and interactivity could improve learning performance, we arranged an experimental study involving 360 children from 16 Uruguayan classrooms. The main purpose of this paper is to describe the authoring and design process that we followed in order to produce the 3 learning object formats which were used for the tests (Infographic Resume, Step by Step Multimedia, Learning-Game).

Keywords
Instructional content design, ADDIE, problem based learning, game based learning, multimedia learning, learning object, early adolescence.

1. INTRODUCTION
This paper presents the Instructional Content Design process of an experimental study ran in 2010 in order to test learning object[1] formats with kids in "real world" learning contexts. The main goal of the study is to find out effective ways to use infographics and interactivity for digital scientific contents to reduce cognitive load[2] and increase learning performance. The second goal is to identify the best use of multimedia contents in classrooms comparing 3 different learning settings: individual self-directed learning, cooperative learning and traditional frontal lesson.

1.1 Research methodology
Uruguay was chosen as research field because of its unique educational system[3] that aims to provide analogical and digital writing skills to the primary school students by the implementation of the OLPC program. The - *One Laptop per Child* - project started in 2005 at the MIT-Media Lab in Boston by Nicholas Negroponte and Seymour Papert[4]. The aim was to develop a low cost laptop pc model called XO (with a price lower than 100$) and to distribute it in the schools of developing countries. These models were made to boost children's learning according to instructional principles of constructionism, learning-by-doing and social constructivism theories. Uruguay is an "en plein air" research laboratory with a vast scholar sample: 510.000 XO personal computers[5] have been distributed to primary school children and teachers. Our experimental study evaluates the impact of content design on the achievement of specific instructional goals by developing and testing 3 analogical and digital Learning Objects (LOs) to assess how information display methods and interactivity levels can affect learning in pre-adolescents.

We ran the tests with a population sample of 360 subjects from 16 classrooms of the capital Montevideo. The students (11-13 years old) had not previous knowledge of the instructional content and no impairments concerning the use of XO laptop.

1.2 Theoretical background
The Cognitive Theory of Multimedia Learning (ML)[6] and First Principles of Instruction (FPI) of D. Merrill[7] are the theoretical frameworks for the content design process in order to discover which LO format promotes meaningful learning processes in pre-adolescent students.

2. INSTRUCTIONAL CONTENT DESIGN MODEL
In order to develop and test the learning materials we adapted the ADDIE Instructional Design Model (five-steps consisting of: Analysis, Design, Development, Implementation, and Evaluation) as an Instructional Content Design iterative cycle. The process involved our design team (composed of an instructional designer, a psychologist, a graphic designer, an animator and an ActionScript3 programmer), 16 primary school teachers and a pilot group of students (N=27). All the actors participated in the adjustment of LOs contents and interactions before the final experimentation. Each phase included several iterative steps followed until a satisfactory output was achieved.

2.1 Analysis
In this exploratory phase we ran a learning environment analysis using a *contextual inquiry* approach to discover how the learners use technology and digital contents in real classrooms. We made interviews and focus groups with 16 teachers and 10 school principals to query users about their direct experiences with LOs and OLPC laptops.

A preliminary research about the state of the art of existing educational materials considered contents in 3 languages: Italian (researchers mother tongue), Uruguayan Spanish (students native language) and English (scientific language), reviewing scientific information publications, literature and web resources. Scientific information publications included textbooks, game-books, popup books, series of science books; literature consisted of science fiction books and novels; web-resources were both on-line sites and downloadable educational games. We approached all of these materials trying to prefer infographics based contents and checking whether Merrill's or Mayer's principles[8] could be satisfied.

Moreover we tried to define, according to the Theory of Cognitive Development by Piaget[9] the correct range of age of the students, as we were supposed to check not only concrete but even hypothetical and abstract thinking. We decided to consider, as a sample survey, the age between 11th and 13th year, matching to the fourth Piagetian stage "Formal operational stage".

2.2 Design

16 teachers were involved as *subject matter experts* in a participatory design process using interviews and focus groups to identify a scientific learning content that were part of the official school program but was not previously treated with the classes. According with them we chose the *food chain process* as main topic including - as prerequisites - the *animal diet* and the *trophic levels*.

In order to define learning objectives according to the type of informational content displayed and the performance level expected by the learner we evaluated different instructional design tools including the classic and the revised Bloom's taxonomy and the Merrill's content/performance matrix (CPM) [10]. We created a new hybrid matrix (see table 1) based on the CPM and the modified version of Clark[11].

The types of information provided in the contents were defined as:

- **Facts:** bits of information that identify specific items (ex. lion)
- **Concepts:** a category of objects or ideas that share common features and have a common name (ex. carnivores include lions, hawks and sharks)
- **Processes:** concern how a system works and operates and how its parts are interrelated (ex. the food chain process).

The adopted levels of cognitive performance are:

- **Remember**: the learner memorizes or recognizes the information provided
- **Apply**: the learner uses new information to solve a problem or perform a task
- **Find**: the learner creates a new schema through reorganization of the concepts.

According to the performance outcomes isolated with the teacher's help, the content design phase was implemented by a small team that produced three multimedia instructional formats:

- **LO1 - Infographics Resume**
- **LO2 - Step by Step Multimedia**
- **LO3 – Learning-Game**

Each of the learning contents displays the same information set and uses a *virtual pedagogical agent* (the character named Prof. Haragan, see Fig.2,3,4) to introduce relevant concepts and processes. The three learning object formats vary in:

- **Instructional Media**: printed material Vs digital content.
- **Instructional Strategy**: Topic Centered Vs Problem Centered learning.
- **Instructional Sequence:** information straight from the virtual tutor Vs provided as a positive feedback from the digital coach.

According to the LO formats, we defined the ML principles to be respected in the implementation phase as follow in table 2.

2.3 Development

The prototyping phase started from LO3, the Learning-Game, because of its internal complexity respect to the others. We made the preparatory storyboards, wireframes and visual mockups, then we proceeded with the design of basic interactions and game mechanics. A small group of *subject matter experts* approved the first rough version, then we implemented prototypes for the 3 formats varying different parameters but maintaining the same infographic charts to display information, the same script and the same virtual tutor, in order to make the different experimental conditions comparable.

LO1 - *Infographic Resume:* this printed learning object (A4, full-colour sheets) displays the information by using visual explanation of concepts and connections between them (see Fig.2). This collection of graphic organizers integrates different media in simple diagrams: text, images, symbols, schemas. The information is presented with a topic-centered approach and by a virtual tutor narration in a comic style format that provides contextual comments and captions for the diagrams. The learner is invited to a step by step construction of the food chain model through a self directed learning strategy without external feedback or guidance.

LO2 – *Step by Step Multimedia* (OLPC Laptop support): this multimedia explanation consists of a *step by step animation synchronized* with the pedagogical agent narration (see Fig.3). This LO implements a *basic interactivity level*[12] to reduce cognitive load. Learners are allowed to review the topics, control the pace of the narrated animation and the order of the instructional chunks. The multimedia message follows a topic-centered approach and incorporates audio, animated diagrams, infographics resumes. Most of the texts are replaced by the human voice of the virtual character. As recommended by Clark[13], *demonstrative instructions* have to show examples of what is to be learned rather than merely telling information. A clear narrative description is integrated with the visual model of of the food chain process and describes each stage stressing (*signaling principle*) the key elements and concepts[14].

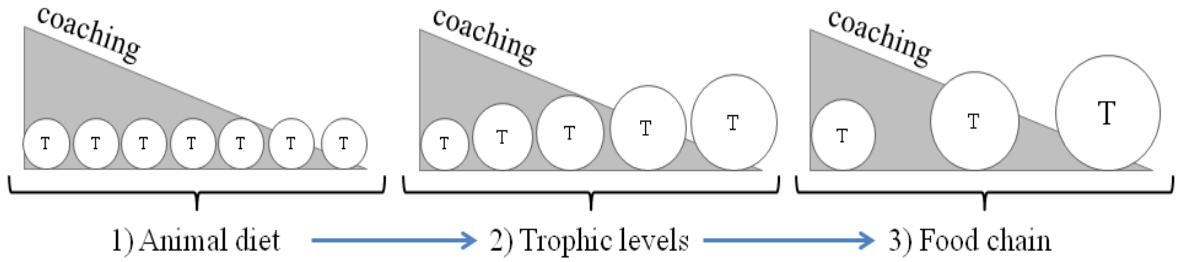

Fig 1: Task-Centered Instructional Strategy and fading guidance in the interactions in LO3.

LO3 – *Learning-Game* (OLPC Laptop support)**:**

Instructional Design: ML principles for information display are the same for both, LO2 and LO3. They significantly differ by the adopted instructional strategy (see Fig.4). LO3 is a sequence of 3 Learning-Games based on Merrill's Task Centered Principle (see Fig.1): "…performance is enhanced when learners undertake a simple-to-complex progression of whole tasks with a corresponding decreasing amount of learner guidance and coaching…"[15].
In the *activation phase* the learner is invited to apply relevant cognitive structures by making inferences on the solutions; considering that learners have limited prior information, the instruction provides relevant challenging experience that can be used as a foundation for the new knowledge.

Merrill's *Application Principle*[15] says that "Learning is promoted when learners engage in application of their newly acquired knowledge or skill that is consistent with the type of content being taught. Learning from an application is effective only when learners receive intrinsic or corrective feedback. Learning from an […] application is enhanced when learners are coached and when this coaching is gradually withdrawn for each subsequent task".

As in LO2, in the *demonstration phase* the tutor synthesizes the topic with multimedia messages using synchronized audio, animated diagrams, infographics resumes. Most of the texts are replaced by the human voice of the animated character.

Game Mechanics: the virtual tutor (the animated character) invites the learner to become a young scientist passing through activities related to the main topics. The flow of the problem-centered game is conditioned by the right solution of previous tasks; the virtual tutor delivers objects and symbolic rewards when the learner passes to the next levels (notepad, camera, camcorder, lab alb, final certificate and medal).

Interactions and Learner Control: the implemented Learning-Games consists of two *classification activities* for animal diet and trophic levels topics and three *rollover/drag n' drop exercises* for active construction of food chains. Learner is allowed to review topics, control the pace of the narrated animation and perform the problems tasks several times.

Feedbacks: before every activity, the virtual tutor introduces the topic and the rules, challenging the student to solve the problem without previous information. During the interaction, the tutor provides minimal negative feedback in order to guide toward the right answer and uses significant positive feedback when the learner completes part of the task. The real reward offered by the game is the acquisition of new information about the topic. The progression is conditioned by the engagement of the student in solving the problem and creating the knowledge model.

2.4 Implementation

We submitted LO2 and LO3 prototypes to a pilot group of 27 subjects to identify interaction design problems and implementation errors; the results of this test became the first step of an iterative re-design cycle before the final implementation rollout.

2.5 Evaluation

In this final phase we assessed the impact of instructional content format on learning results submitting to the sample 4 tests:

1) **Retention Test** - checks the ability to remember the most important parts of the material;
2) **Comprehension Transfer Test** - aims to measure the ability of classifying new examples and the comprehension levels of the main concepts presented;
3) **Problem Solving Transfer Test** - asks the student to transfer *the food chain model* to unknown environmental contexts performing a few problem solving tasks*;*
4) **Problem Solving Transfer Re-Test -** the same problem solving test evaluates one week later the ability to apply the food chain model learnt with the LOs;
5) **User Experience (UX) Questionnaire** - a qualitative tool built to discover relationships between students preferences, satisfactory learning experiences and learning achievements.

Table 2. Adapted Content/Performance Matrix.

	FACTS	CONCEPTS	PROCESSES
Remember	**Remember specific data and facts.** Ex. recall the names of the animals shown in the learning material	**Remember and understand definitions** Ex. define the meaning of these classes: herbivores / omnivores / carnivores; producers / consumers / decomposers	-
Apply	-	**Apply and transfer the concepts classifying new, unknown examples** Ex. classify animals and other living beings belonging to unknown ecosystems applying new information (about diet and trophic levels)	**Solve a problem by relating the acquired concepts in the right way** Ex. use concepts of animal diet and trophic levels for the construction of new food chains
Find	-	-	**Reorganize existing concepts to derive a new abstract scheme** Ex. represent the food chain process in a new abstract scheme

Table 1. Multimedia Learning principles and LOs formats.

		LOs formats		
Goal	**Multimedia Learning Principles**	**LO1 Infographic Resume**	**LO2 Step by Step Multimedia**	**LO3 Learning game**
Reducing Extraneous Processing	Coherence	✓	✓	✓
	Signaling	✓	✓	✓
	Redundancy	✓	✓	✓
	Spatial contiguity	✓	✓	✓
	Temporal Contiguity	×	✓	✓
Managing Essential Processing	Segmenting	✓	✓	✓
	Pre-training	×	×	×
	Modality	×	✓	✓
Fostering Generative Processing	Multimedia	✓	✓	✓
	Personalization	✓	✓	✓
	Voice	×	✓	✓
	Image	✓	✓	✓
	Interactivity	✓	✓	✓

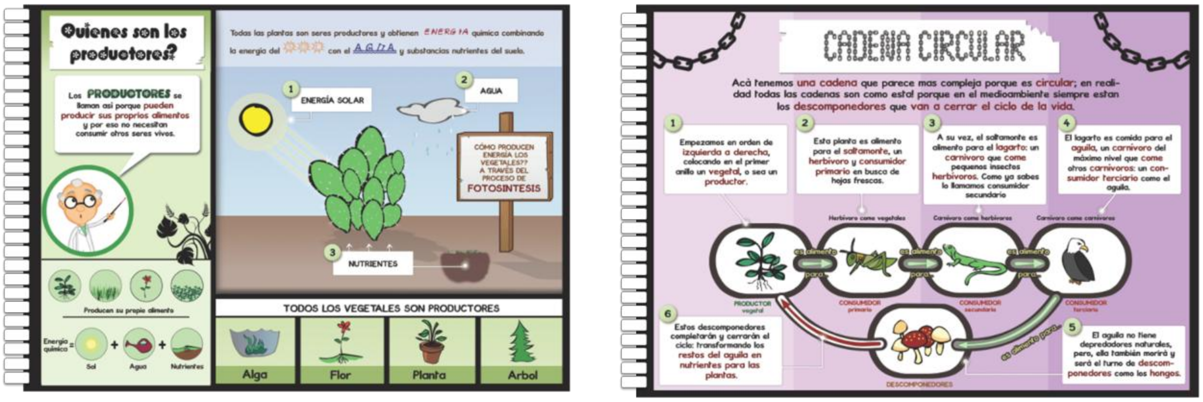

Fig 2: Screenshots of LO1 – Infographic Resume.

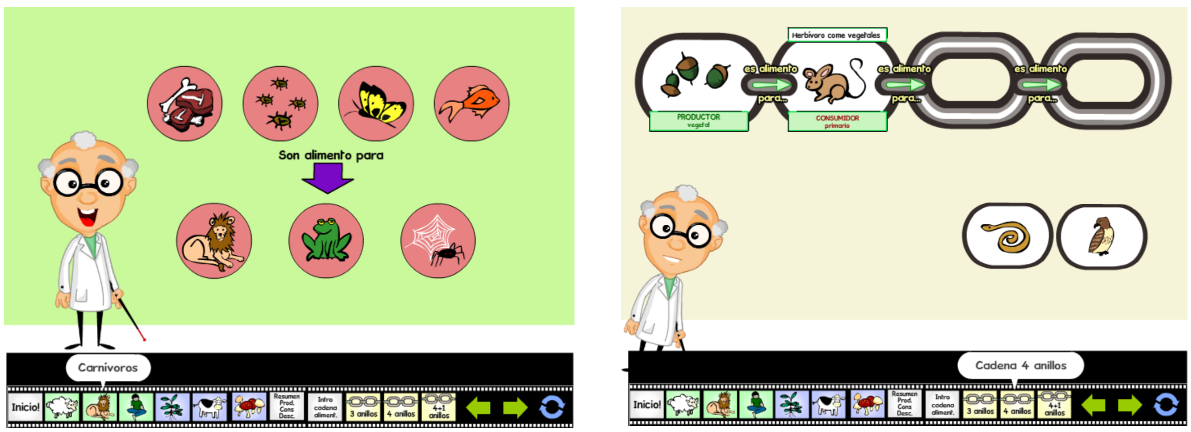

Fig 3: Screenshots of LO2 – Step by Step Multimedia.

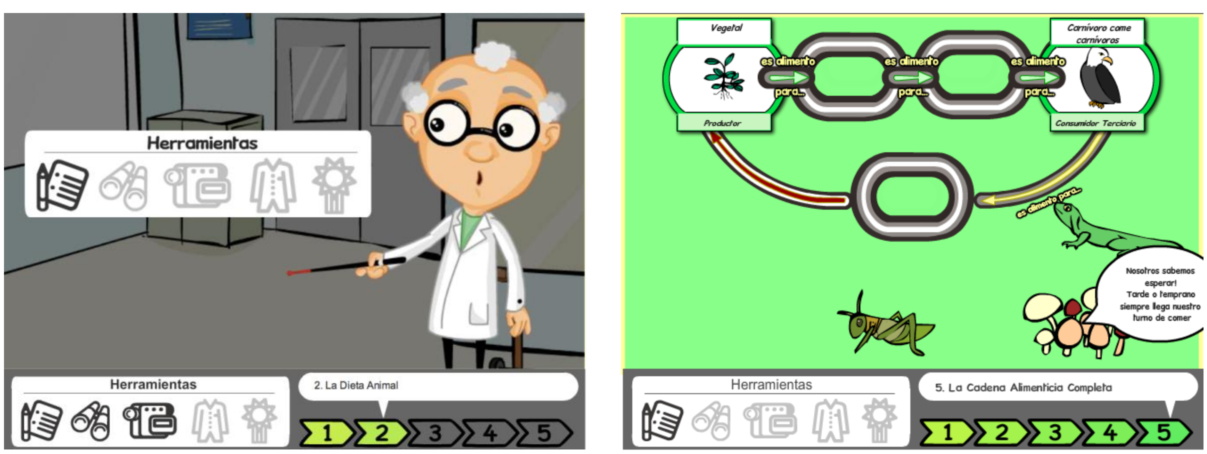

Fig 4: Screenshots of LO3 – Learning-Game.

3. CONCLUSIONS

In this paper we describe only the LOs design process avoiding to present any preliminary result of the research, as long as the statistical analysis is still ongoing.

The primary goal of this study is to experimentally evaluate the differences in terms of effectiveness for each of the three LOs formats presented, considering as the basis for the design both the scientific evidence (ML and FPI) and the engagement of students for the proposed formats (UX).

We believe that self-directed learning in real contexts equally depends on the adoption of appropriate instructional strategies (topic-centered Vs. problem-centered) and a satisfactory learner's User Experience.

Consequently we introduced a virtual pedagogical agent to support the subjects through the learning process letting them converging the attention on relevant visual explanations (infographics) that offered integrated analysis, synthesis visions and increased the aesthetic satisfaction.

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