Design techniques to enhance e-Learning strategies for primary science: The case study of EDUciencias smartbook

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Abstract

The focus of this research is to investigate how science concepts are introduced when using e-learning at elementary schools. This is important because the use of technology to assist teaching has been proven beneficial and it is being promoted around the world. Understanding what considerations should designers take into account when designing this kind of instruction, can help to develop successful e-learning environments. The research approach adopted in this dissertation includes a literature review to identify the strategies to enhance learning that are being proposed by the learning sciences, and a systematic analysis of the case study: EDUciencias, an Uruguayan smartbook to support the science national curricula in the classroom. The findings from this research provide evidence that e-learning instruction is multimodal, and its objectives are similar to the ones of information design; that there is a relation between the product structure and the learning theory behind it; and that the strategies suggested by the learning sciences can be applied with design techniques on a micro, macro and meta level but they are affected by the context of use. This dissertation recommends designers to incorporate the knowledge generated by the cognitive and behavioural sciences, and psychology as a valuable input to design e-learning environments. Furthermore, there is a recommendation for further studies on the effectiveness of the techniques applied by the case study described above.

Contents

Chapter 1 Introduction

1.1 Background

E-learning has opened many doors to expand education. Some education philosophers like Ivan Illich envisioned education being enhanced by internet and technology. These ideas are behind projects like the *One Laptop per Child*, a non-profit project where kids from developing countries receive a computer to empower them in their education (One laptop per child, 2016). This enthusiasm, shared by many educators, has created different strategies whose objective is to enhance learning using technology. Virtual classrooms, video tutorials, online communities, CDROMs and eBooks, to mention just a few, represent new tools focused on supporting learning.

E-learning was expected to be more efficient than live teachers or other media (like books or television). It, was also expected to be more motivating, to accommodate various learning styles maximising learning, and to give autonomy and control to students, among other good attributes (Clark & Mayer, 2011). However, e-learning success is not guaranteed;, as any other innovation it is related with good practices, research and appropriation.

E-learning did not reach its expected growth at the beginning of the century (Mason & Rennie, 2006). However, its usage is still rising (Clark & Mayer, 2011) and there are many good examples and projects around the word. It is present in government's agendas because technology-assisted education has proven beneficial for primary schools as well as for higher education and distance learning (Byrne & Sharp, 2015; Peters, 2014).

Nevertheless, to achieve the full potential of technology in education more research and studies are needed (Clark & Mayer, 2011). Clark & Mayer (2011), Hsi & Soloway (1998), as well as Peters (2014), have emphasised the importance of a learner-centred approach. They prioritise the design of this technology in a different way to finally address the distinctive needs of learners.

1.2 Research focus

The research focus is to investigate how science concepts are introduced in e-learning at primary school level. There are many dimensions to study related to e-learning: social interactions that take place through the computer, learning tasks

proposed like exercises or activities, strategies to motivate and engage students, the interface control and personification, assessment techniques, and also instruction exposition to remark a few. Particularly, as this work is part of a master in Information Design the focus would be in the actual display of information, this means the instruction exposition, often referred to as a lecture.

Exposition is one part of the e-learning environment, and it is the delivery of information to learners. It is mainly a one-way interaction but it might include the participation of the learner with questions, by choosing the content and the form that exposition takes. Learners can interact with the information in many ways (Hubbard, 2013). The instructional material is the form that the exposition takes, and in e-learning it is sometimes called multimedia learning material because it naturally takes advantage of different media. Namely images, text, audio, animations, or video, when used together, are proven to be more efficient than using only words or images (Mayer, 2014).

This project focuses on how to present scientific information in the classroom using technological devices at the primary school level. Specifically, the project is intended for children capable of autonomous reading (students that can read fluently by themselves) which is usually achieved at eight or nine years of age.

1.3 Overall research aim and individual research objectives

Two research questions motivate this work:

- How Science concepts are presented in an e-learning environment like EDUCiencias?
- What considerations should designers take into account to enhance learning?

The overall aim of this research is to explore the information design of e-learning environments introducing science concepts for children through a particular example. The case study is EDUCiencias, an Uruguayan smartbook used in the classroom supporting the national science curricula. However, to achieve the research aim it is has been divided into different research objectives:

1. *Gather* all relevant matters to understand and *identify* strategies to enhance the learning of science concepts for primary school children in e-learning.
2. *Construct* a framework for analysing an e-learning environment.
3. *Analyse* and *outline* some of the design considerations for enhancing learning in EDUCiencias.

Objective one will try to gather all the relevant matters to understand and analyse how to enhance learning through design. Objective two will structure the method used to analyse the case study. Objective three will apply the knowledge acquired in an analytical and constructive way. These objectives are not meant to be seen as independent, but rather as all linked to issues surrounding e-learning instructional design to support the understanding of science by children.

1.4 Outline research methods

The following research methods will be applied. First, the survey will start with a

literature review to understand and exhibit what was already written about this topic in particular, and to define key terms that will support the work. Then an analytical framework will be created to analyse e-learning environments. That framework will be applied to a case study because it is important to use a real word example to examine how and which strategies are implemented in a specific product.

1.5 Value of this research

This research work will hopefully contribute to e-learning development by:

- providing a critical review of pertinent issues for the implementation of e-learning, particularly in the introduction of science concepts from a design point of view.
- creating a framework that summarises the strategies of designing to enhance learning, which could be useful to other designers interested in addressing the learner's needs.

The next chapter examines literature that defines e-learning, investigates how humans learn and finally what issues are important to teach science to children, to be able to understand e-learning strategies to enhance science learning.

Chapter 2 Literature Review

This literature review will introduce the main features of e-learning environments. It will present what is known about how we learn, some of the particularities of e-learning as a way of instructing knowledge, the design approach for it called learner-centred design, and general implications of teaching primary school science. Finally, it will outline main reasons why e-learning should be approached from an information design point of view. Some strategies to enhance learning through design techniques will also be presented.

The study within this review of literature seeks to fulfil the first research objective and set the ground for the second one, both listed below:

1. *Gather* all relevant matters to understand and *identify* strategies to enhance the learning of science concepts for primary school children in e-learning.
2. *Construct* a framework for analysing an e-learning environment.

This chapter would also define the key concepts for this dissertation, drawing references from learning sciences, e-learning designers and the special requirements of science teaching to primary school children. This chapter aims to form a critical understanding of how children learn and how their learning could be enhanced in online environments for teaching science.

2.1 What is e-learning

Before looking at how e-learning can be enhanced, it is important to understand what learning is. Learning refers to knowledge integration; according to Clark and Meyer (2011), there is an agreement between learning scientists who understand that learning occurs when the learner's knowledge changes as a result of an experience. This definition points out that the nature of learning is change, the transformation of knowledge and an experience. Learning as an experience has been especially important in the understanding of learning as not only a cognitive subject but also a sociological phenomenon, where motivation and context take an important role (Norman, 2004; Peters, 2014).

E-learning can be defined in many ways. Some authors understand e-learning as instruction that makes use of internet technologies (Mason & Rennie, 2006). Nevertheless, although the internet is widely used in teaching and learning, it seems

more reasonable to consider Dorian Peters's (2014) conception of e-learning as "an umbrella term for learning experiences that involve digital technology" (p. 4). Likewise, Clark and Mayer (2011) define e-learning as "instruction delivered on a digital device such as a computer or mobile device that is intended to support learning" (p. 8). Thus, what is unique to e-learning, and what separates it from traditional learning, is just the how: via a digital device.

Multimodality

E-learning is strongly associated with multimedia. Sometimes 'multimedia environment' is used as a synonym of 'e-learning environment'; this could be due to the easy integration of text, graphics, sound, video or animations provided by technology. This integration is called by semiotics the use of multiple modes (Jewitt & Kress, 2008).

Multimodality has proven to be more efficient than just using one mode for delivering information (Clark & Mayer, 2011). While in digital devices multimodality is implemented by multimedia material, in schools multimodal communication is always provided by teachers' postures and gestures or using instructional materials such as images, posters or books (González & Salsamendi, 2016).

Designers have a particular interest in multimodality; graphic designers especially in graphic multimodality as this is their subject matter. Many authors have described the power of images, the importance of the relationship of them with text or other modes to deliver effective messages (Hartley, 1994; Neurath, 1936; Twyman, 1979; Waller, 1985). This specialisation makes designers useful professionals for the development of multimedia instructional material.

Blended learning

Learning can take place and be distributed in many ways and contexts. Depending on the delivery channel it could be distance, online, face-to-face, or blended learning. E-learning also gives the possibility of asynchronous or synchronous learning Furthermore, it can involve tutors or be self-explanatory for independent learning that is when the learners interact only with the device or each other. In her book, *Interface Design for Learning*, Peters (2014) refers to this diversity as the 'eLearning landscape', and she emphasises that there are not clear boundaries between the different types.

Diverse forms of instruction have different requirements for the design of the environment. This needs to be considered during the development or analysis of the systems depending on each situation (Hubbard, 2013).

One type of e-learning is blended learning. It is generally referred as a mix of complementary teaching methods delivered, where one of them is digitally-based. Digital technology in this context is used to generate a more engaging and efficient experience than traditional classroom learning (Hubbard, 2013). This type of delivery is the focus of this dissertation because there is clear evidence of its effectiveness (Byrne & Sharp, 2015).

Table 1 The three metaphors of Learning (Clark & Mayer, 2011)

Metaphor of learning	Learning is...	Learner is...	Instructor is...
Response strengthening	Strengthening or weakening associations	Passive recipient of rewards of rewards and punishments	Dispenser or rewards and punishments
Information acquisition	Adding information to memory	Passive recipient of information	Dispenser of information
Knowledge construction	Building a mental representation	Active sense maker	Cognitive guide

In e-learning, there are three different kinds of interactions and all of them are necessary for an effective learning experience: the learner with other participants interaction (i.e., other learners or the teacher); learner-interface; and learner-content. There is even a theory that goes further and describes an interaction between the learner and the course designer (Sims, 2012).

However, in blended learning instruction, the interaction with other participants is face-to-face and not through the e-learning environment. The relevant interactions to be designed are the learner-content and learner-interface. Particularly this work will focus on the learner-content interaction,

Learning theories

Instruction always takes place within a general theory. There is no way of truly condensing all the content generated by sciences and psychology. However, it is possible to summarise two basic ways of envisaging the learner: the objectivist and constructivist. Objectivists see the student as an empty vessel, and the teacher is in charge of imparting the knowledge. Constructivists see the student as a 'builder'; the knowledge is constructed by him as the teacher is considered a facilitator (Peters, 2014). Many authors (Clark & Mayer, 2011; Mason & Rennie, 2006; Peters, 2014) seem to agree that Constructivism is the theory most implemented in learning technologies, enhancing the independence and autonomy of pupils. Technology, on one hand, gives the possibility to learners to have control over their learning experience, and conversely, it has a huge potential through the Internet, to build communities where learners can socialise, help each other and get involved. In other words, technology can facilitate student's active engagement with learning.

There appears to be a parallelism between constructivism, learner-centred and user-centred design. Constructivists seems to put the learners in the focus, and then the instruction is delivered depending on their requirement and capabilities; user-centred design does the same although not specifically for learning (Norman, 1990). Learner-centred is a user-centred approach focused on learner needs. The learner-centred approach is shared by many authors (Hsi & Soloway, 1998; Norman & Spohrer, 1996; Mayer, 2014) and underscores the importance of understanding the characteristics of learning to design for instruction.

The Constructivist understanding of learners as active actors ('builders') in their instruction is reflected in the third metaphor of learning (Mayer, 2014) where active learning is needed for knowledge construction. In Table 1 the metaphors and the roles of learner and instructor are summarised.

How we learn

After defining e-learning and how the learner is conceived, it is now important to understand learning. There are three aspects related to it: acquisition of knowledge, memory's limitations, and motivation (Mayer, 2014).

Figure 1 Cognitive Theory of Multimedia Learning (Clark & Mayer, 2011)

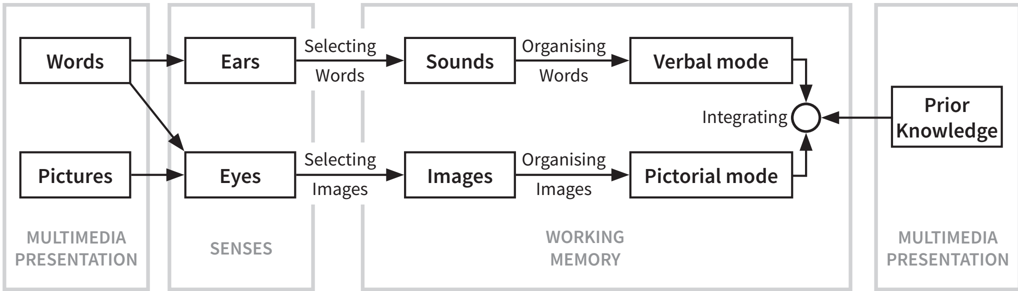


Figure 2 An attempt by Twyman to accommodate the different approaches to language (adapted from Twyman, 1985)

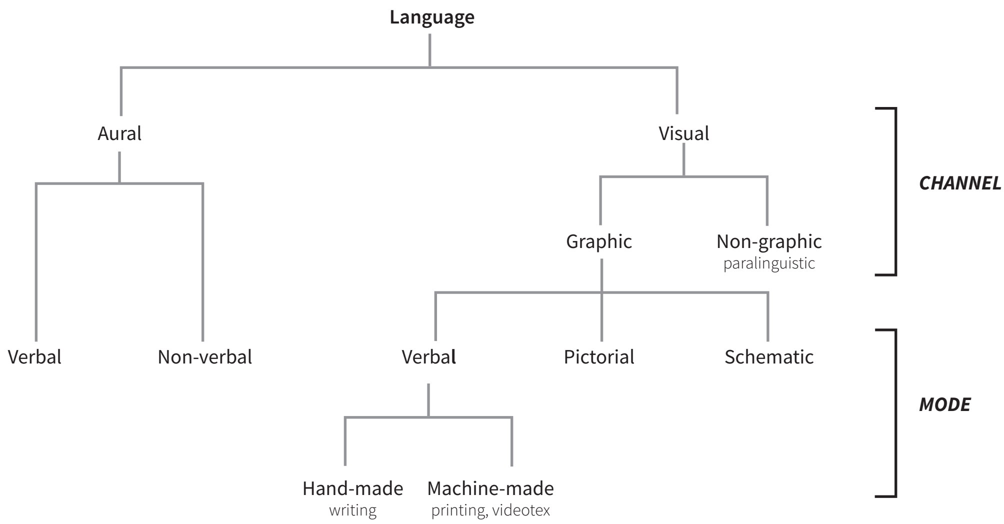
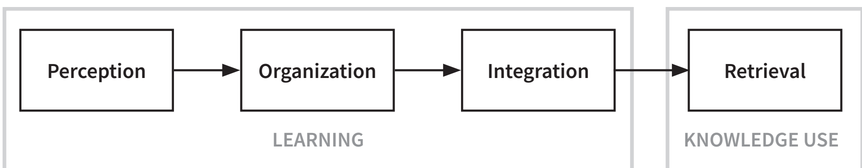


Figure 3 Learning process



To understand how knowledge is acquired, how is that process, cognitive sciences divide it into five stages:

1. Selecting words
2. Selecting images
3. Organizing words
4. Organizing images

The diagram in Figure 1 illustrates the process of learning and demonstrates it is an active one. It also shows the importance of memory and prior knowledge for making the connections that will construct the knowledge. The diagram also shows that learning takes place through two channels: a verbal and a non-verbal. This diagram also implies the potential importance of graphic designers' role in instructional design as creators for the visual channel principally.

The graphic designer Michael Twyman (1985) shares this dual channel view. He suggests aural and visual information takes place in most communicational situations. Furthermore, he suggests that designers study, within the visual line of language, the graphics representations of language. Figure 2 represent his understanding.

To put it more simple, the learning process it has three main steps, the perception of the information through words and pictures (the two channels), the organisation of that information, and then integration of it in prior knowledge. Once those steps are achieved the learner should be able to retrieve that information. This process is summarised in Figure 3.

The cognitive sciences understand that our mind has a limited capacity in memory and attention (Mayer, 2012). This result in demands in each of the learning steps, the three demands of our cognitive capacity that take an important place in learning are:

> "*Extraneous processing*—is cognitive processing that does not support the instructional objective and is created by poor instructional layout (such as having a lot of extraneous text and pictures);
>
> *Essential processing*—is cognitive processing aimed at mentally representing the core material (consisting mainly of selecting the relevant material) and is created by the inherent complexity of the material; and
>
> *Generative processing*—is cognitive processing aimed at deeper understanding of the core material (consisting mainly of organizing and integrating) and is created by the motivation of the learner to make sense of the material." (Clark & Mayer, 2011, p. 37)

Finally, motivation takes an important role because learning is an emotional activity (Hsi & Soloway, 1998; Norman & Spohrer, 1996). This means that the engage-

ment with learning will condition the learners' attention and their actual knowledge integration. Deci and Rayan (1975) claim that motivation could be intrinsic or extrinsic. Intrinsic motivation is related to naturally enjoyable activities, and extrinsic motivation relates to doing something that will achieve a separate outcome (as cited in Peters, 2014). Peters (2014) argues that despite both are important; extrinsic motivation has some limitations. For this reason, it is always better to try to reach intrinsic motivation that can be related to human beings motivators, such as autonomy, mastery, competence, connectedness and purpose, among others.

Therefore, the three aspects involved in knowledge acquisition introduced in this section are:

- **The memory system** studied by psychological sciences and represents the limitations of the mind.
- **The information processing system** studied by cognitive theories and explains the process of integrating knowledge.
- **Motivation** studied by behavioural sciences to engage learners in active learning.

2.2 Designing e-learning for children

E-learning environments making good use of multimedia material can be very beneficial for kids as they can be illustrative and they also could support kids' natural curiosity (Druin & Solomon, 1996). This assumption has probably driven the efforts of designing technology for kids.

To design e-learning for children could be relevant to know what they expect from it. However, it appears to be a lack of references about the design of interfaces for kids. Allison Druin criticises this in her book *The design of children's technology* (1999) and suggests three things children want from technology. First, control, as they feel empowered by it. Then, social experiences that could be online or face to face; for example, they tend to form groups around a computer to share the experience. Finally, an 'expressive tools' as they enjoy different forms of expression. These points were made for any kind of technology not only for e-learning. Nonetheless, they are also relevant for learning technologies for children.

Druin (1999) regrets some designers think that designing for children is only adding colours and loud sounds; in reaction, she points out what kids notice from technology. They care about what is 'cool' in technology; they also want what others have, and they are sensible to trends. They also note how easy they learn with multimedia tools and how many multimedia does the tool provide as they genuinely enjoy multisensory experiences. Furthermore, they seem to be sensible to aesthetics, enjoying aesthetic-pleasant environments. Children are commonly underestimated as users but with these statements Druin tries to show that they should be considered as any other user.

Moreover, usability research in designing computational products for children is as important as it is for adults (Druin, 1999). There are many usability methods such

Table 2 User interface guidelines for children's computer products (Adapted from Druin, 1999).

Areas of product design	Guidelines for design	Further information
Instruction	Present instructions in an age-appropriate format	Children and not used to read text on screen, they would not read it if it is not totally necessary
	Design instructions to be easy to comprehend and remember	Language should be simple and clear, be careful not to include concept they have not learn yet. Highlight elements mentioned in the instruction.
	On-screen character intervention should be supportive rather than distracting	Young children pay more attention to on-screen characters giving instruction that only audio. But, they need to be coordinated with the instruction, to prepare the learner for what is coming, and if there is more that one they shouldn't compete or talk at the same time.
	Allow children control access to access to instructional information	They should be able to stop animations. Instructions can be repeated in form of feedback or with help features.
Screen layout	Design icons to be visually meaningful to children	Best icons for children are representation of everyday objects for them. If clickable make them look clickable using 3D. Don't have a /return' and a 'quit' button on the same window, they tend to use the 'quit' one
	Use cursor design to hep communicate functionality	Make use of the three states of the cursor: resting, 'hot' and 'waiting'. Use for them metaphors that the kid will find familiar.
	Use roll-over audio, animation and highlighting to indicate where to find functionality	This way they can see what is clickable or not. It is important to coordinate animations or audio with the cursor so they can make a correct connection.

Table 3 Piaget's stages of development (adapted from Peter's, 2014)

Stage	Period (commonly between)	Characteristics
Sensorimotor	birth to 2 years	We construct our understanding of the world based on information from our senses and movement.
Pre-operational	2 to 7 years	We are self-centred and can act on objects and represent them with words and symbols, but we cannot fully think through our actions.
Concrete operational	7 to 11 years	We can use logic to solve actual nonabstract problems and we discover that viewpoints beyond our own exist.
Formal operational	12 years and more	We can think abstractly, hypothesize and draw conclusions

as card sorting, paper prototypes, site visits, and surveys to use to design for and with children, as they are the ones that actually know what they want. Druin (1999) illustrates this with many examples, and she highlights the advantage that they are willing to participate.

In addition, she proposes some guidelines for the design of children's technology; the relevant guidelines for this survey are summarised in Table 2. The table shows general guidance that could be beneficial in the design of e-learning environments for children. As mentioned before, these directions cannot be extrapolated without context, they are just another input for the design. Further testing is necessary to fit a particular project.

As seen in the table, Druin proposes to take considerations for children equally than for other users. However, she also points out the importance of using pictorial representations of familiar objects or metaphors of our word rather than using abstract graphics. She also highlights the importance of using characters, and how to do it. All this she points out is closely related, with children's cognitive development introduced below.

How Children learn

Most of the educational theories related to children's development, accept Piaget's (1970) Cognitive Constructivism, where he explains the different stages of human development (as cited in Peters, 2014). He understood that human's learning always moves through four progressively sophisticated stages while growing up. The following table (Table 3) presents Piaget's stages of development.

The other notable theory regarding children's learning is the 'zone of proximal development' coined by Lev Vygotsky (Peters, 2014; Bransford, Brown, & Cocking, 1999). The theory claims, that besides the importance of self-development and self-motivation, others serve as guides helping children to achieve things that they would not otherwise achieve alone. Vygotsky emphasises in the active and social nature of children learning, but Wright and Huston (1995) went further. They believed that not only people can be guided, other tools can also be. Take other cultural artefacts as an example, notably television, books, videos, and various technological devices (as cited in Bransford, Brown, & Cocking, 1999). This theory supports the importance of educational material in children's learning process.

These two theories give a clear understanding of children cognitive development and sent precedents to base the design of e-learning environments. In this context, it is important to look especially into how children learn sciences and the peculiarities of this subject of knowledge.

2.3 The drive of e-learning in science for children

Primary science seems to be a good area to apply e-learning for many reasons. There is evidence that it improves performance; as a tool technology gives special opportunities to sciences due to the scientific discourse characteristics; and nowadays there is also a political factor involved.

The British Education Communication and Technology Agency (BECTa), using a range of different sources, found that schools that used technology resources for teaching sciences are achieving higher standards (Byrne & Sharp, 2015). Teachers using technology in class aid children's learning. A successful example of this in blended classrooms was studied in 2009 by SEG Research. They run an experiment to measure the effectiveness of BrainPOP, a web-based animated instructional tool. The research showed better improvement in the knowledge of sciences in the classes that used BrainPOP in comparison with the ones that did not (Elliot & Stubbs, 2010). These observations strongly suggest that e-learning can improve knowledge acquisition in sciences at the primary school level.

Another reason for the suitability of multimedia for science, is the scientific discourse itself. Lemke (1998), suggests that it is a multimodal discourse because to fully describe any scientific concept it is necessary to use simultaneously: verbal, visual, mathematical and actional modes (as cited in González & Salsamendi, 2016). According to this view, multimedia computational resources are convenient to communicate scientific concepts.

E-learning environments provide specific opportunities to science education. Byrne & Sharp (2015) lists the main opportunities for the use of ICTs as follows: opportunity to model some of the way scientists work; to provide access to rich and varied source materials; to speed up processes that would normally take time; and to allow safe access to difficult, costly, or hazardous activities.

Furthermore, the use of ICTs (Information and Communication Technologies) in education, and especially in science, is globally on the public agenda. Two examples of this are UK (Byrne & Sharp, 2015) and Uruguay (Argentina, UNICEF & Vaillant, 2013) that promote their use in primary school. One of the reasons of the promotion is because they understand that "children should have the opportunity to use ICT as they will be expected to live and work in a world ever denominated by it" (Byrne & Sharp, 2015, p. 15).

Children learning science

Children are a special group of users; they have some cognitive and social features that make them have a particular attitude towards science. Druin and Solomon (1996) highlight some characteristics to consider for the design of multimedia environments: their natural curiosity and their love of repetition, but only when it is under their control.

These attributes seem to be reflected in their attitude to approach science. Children in most cases enjoy practical science, to solve problems, and to understand how the world works (science concepts): is fascinating for them (Loxley et al., 2013). Their natural curiosity combined with their pleasure experienced finding out things makes learning science exciting for them. To maintain their enthusiasm, it is necessary to remember their active learning characteristics and involve them in the discovery. Learning science is a creative thinking activity that they find fun.

On the other hand, learning primary sciences represents many challenges to scholars (Loxley et al., 2013). First, there is a difficulty in the vocabulary, as scientific knowledge requires a new jargon that could be entirely new to the child. Also, some scientific explanations can be counterintuitive, because they might interfere with their everyday observations. For example, it is easy for a kid to think that a rolling ball that needed force to start moving, stops because it has run out of force; instead of thinking that other forces acting on it, namely friction, that make the ball stop. This explanation seems quite abstract and is related to another difficulty in learning; school-age children are in a developing stage where they are not able to fully understand abstracts ideas, they need concrete examples to be able to apply logic. Therefore, there is a lot to learn, and it is easy to get it wrong as scientific terms, cognitive limitations and counterintuitive explanations are related to learning science.

Teaching sciences for children

There are many aids to help scientific learning. Engagement is crucial, and one of the ways to do so it is to ask them questions and introduce concepts with storytelling. Using familiar scenarios, different examples, and analogies help them to grasp the concepts; with these techniques the concept is taken into existence, is visualised and applied to practical situations by children. Kids also like to give their opinion, and explaining their ideas help them to clarify and order their prior knowledge, as well as evidencing miss-conceptions (Loxley et al., 2013).

Based on the difficulties and characteristics presented on how children integrate new concepts in their previous knowledge, the following framework has been developed to organise how children learn science (Loxley et al., 2013). The following list enumerates and describes the three-stage model:

1. **Exploratory stage**. Setting the scene and discovering the puzzle. Here children are asked about their ideas about a topic, and they should be convinced of the importance of a scientific view. Scientific enquiry is also encouraged.
2. **Re-describing stage**. Its aim is to make sense of scientific ideas. There is the usage of empirical evidence to create or adapt their old mental models about a topic. They are also persuade to appreciate scientific explanations to make sense of our world.
3. **Application stag**e. Allows kids to try out and experience the new knowledge. They retrieve their new understanding in other contexts.

In Uruguay, CEP (Consejo de Educación Primaria) is in charge of guiding education at primary school stating the aims and objectives at this level. Science, named as ‘Knowledge of Nature’ because it studies the phenomena that occur in nature is commonly named as ‘Natural Sciences’. Scientific knowledge is essential to understand that phenomena and develop children’s critical thinking (CEP, 2009). To approach science and help children to associate which aspect of nature to study, it is divided into disciplines, also called branches of natural sciences:

Table 4 Principles and strategies to enhance learning

Goal	Principle	Explanation	Strategy	References
MINIMISE EXTRANEOUS PROCESSING Direct attention and decrease extraneous processing	Coherence	People learn better when extraneous material is excluded. This way they do not need to make-sense or evaluate to discard information that is not important to the topic.	Add only related material (audio or graphic)	Clark & Mayer, 2011; González & Salsamendi, 2016; Mayer, 2014
	Signalling	People learn deeper if there are cues to highlight organisation and essential material. This offers them navigational support.	Highlight essential material	Clark & Mayer, 2011; Mayer, 2014;
	Redundancy	Redundant material interferes with learning because it uses working memory load for the same information.	Do not use spoken and written text at the same time for explanation.	Clark & Mayer, 2011; Mayer, 2014;
	Spatial Contiguity	Learning is deeply when related images and words are presented near to each other. If they are not, people need to use extra cognitive resources to match them up.	Position related text and graphic, and words and graphics near to each other	Clark & Mayer, 2011; Mayer, 2014;
	Temporal Contiguity	Learning is deeply when related images and audio are presented at the same time. If they are not people need to use extra cognitive resources to match them up.	Present narration and graphics simultaneously	Clark & Mayer, 2011; Mayer, 2014;
	Simplify explanatory visuals	People learn better from visuals with simplified forms; they let them focus on important details. But remember that children find difficult to understand abstraction.	Reduce visual elements	Kali & Linn, 2008; Peters, 2014
MANAGE ESSENTIAL PROCESSING Reduce content complexity understanding mind limited capacity	Multimedia	Learning with words and graphics is better than only with words. This is based on the dual channel theory that explains that humans have two separate channels to process information, and they can work at the same time.	Include words and graphics rather than only words	Clark & Mayer, 2011; Mayer, 2014
	Modality	Deliver words in audio instead of on-screen text can generate significant learning gains. Specially if there are also graphic, this way the visual channel is not overload.	Use audio rather than on-screen text	Clark & Mayer, 2011; Mayer, 2014
	Pre-training	The learner could be overwhelmed by the amount of essential processing needed to comprehend complex lessons. Complicated material could be more understandable by assuring the most important concepts are known first.	Introduce key concepts and specific vocabulary first	Clark & Mayer, 2011
	Segmenting	Complex material is easy to understand if it is divided into simpler comprehensible bits.	Break a continuous lesson or material into manageable segments	Clark & Mayer, 2011
	Limited short memory	Short memory is essential for processing information, but it has a very limited capacity. We can not remember more that 'Seven plus or minus two' pieces of information.	Organize information to stay within memory limits: - Chunk information into 'Seven plus or minus two' -Recode: group chunks of information	Horn, 1989; Clark & Mayer, 2011; Mayer, 2014
FOSTER GENERATIVE PROCESSING Help knowledge integration by engaging learners	Personalization	People make more effort to understand material when they feel they are in a conversation, rather than just receiving information.	Put words in conversation style and use polite speech	Clark & Mayer, 2011; Mayer, 2014; Wendel, 2014
	Voice	People learn deeper when words are presented with human voice rather than a machine one.	Use human voice for audio narrations	Clark & Mayer, 2011; Mayer, 2014
	Embodiment	People learn better when pedagogical agents (virtual coaches or characters) have human attributes, because they feel identified.	Use human characteristics for characters, better if they are similar to learners	Clark & Mayer, 2011; Mayer, 2014; Wendel, 2014
	Image	People do not necessary learn better when the speaker is on screen; but children prefer it.	Not necessary to include a visual character	Druin 1999; Mayer, 2014;
	Storytelling	Stories are a known format for children, aligned with scientific thinking and engaging for them.	Use storytelling	Loxley et al., 2013
	Learner control	The control over the learning experience depends on the prior knowledge of the learner. Novice learners are sometimes not mature enough to make wise control decisions; they also need some more time to acquire knowledge.	Promote self-pacing control in novice learners	Clark & Mayer, 2011; Mayer, 2014
	Prior-Knowledge activation	The activation of prior knowledge has positive effects on learning, as knowledge is integrated into long term memory.	Activate prior knowledge first; make children think about what they already know about the topic	Mayer, 2014; Loxley et al., 2013
	Dynamic visualisation	Not necessarily animations enhance learning more than static pictures.	State the function of the animation (representational or directing function)	Mayer, 2014; Peters, 2014
	Aesthetic-usability	Aesthetics affect emotions and emotions affect learning.	Make the content aesthetically pleasant for your learner	Norman, 2004; Peters, 2014; Wendel, 2014

- Astronomy
- Biology
- Geology
- Physics
- Chemistry

To teach these disciplines, they are divided into many subjects called units, and methodologically it is advised to use a sequential experimental approach where scientific events can be demonstrated, and compared with prior knowledge. This approach is similar to the framework previously presented and tries to boost scientific attitudes such as observation, questioning, curiosity, investigation, and respect for nature and results (CEP, 2009),

2.4 Enhance e-learning

Each aspect of e-learning is relevant but for the aim of this dissertation the work would focus mainly on the information processing system. Notwithstanding, the memory system, and the motivation would be taken into account as they are all interconnected. This interconnection is reflected in the goals of multimedia e-learning stated by Mayer (2014):

- Minimise extraneous processing (directing the attention to the relevant information)
- Manage essential processing (making the content accessible and understandable, taking into account the mind limitations)
- Foster generative processing (help knowledge integration by engaging the student)

This means that the instruction needs to be designed in the first place to avoid cognitive overload, leading the student to what is relevant to the instructional goal. Then, the second requirement is to design to prevent essential overload; the learner is overloaded when the material is too complicated for them to understand. Finally, if the design manages to focus learners' attention on the important things and the content is understandable for them, therefore, the cognitive capacity is available for the generative processing. The challenge here is to help the learner to engage with learning. Fostering generative processing is about motivation.

Strategies to support instruction

To support the presentation of information in e-learning, learners should be guided to detect pictures and words that are presented in lessons; then both are organised to be incorporated into the existing memory (Clark & Mayer, 2011). To support this process, the design of the information should be aligned with the goals of multimedia e-learning introduced before: minimise extraneous processing, manage essential processing, and foster generative processing. Cognitive sciences, psychology and behaviour sciences have developed various strategies to support them. Table 4 summarises the principles related to support the presentation of information and their corresponding strategies to achieve each of the multimedia e-learning goals for children to learn science.

Table 5 Strategies to enhance learning supported by design techniques

Goal	Principle and strategy	Design techniques	Reference
MINIMIZE EXTRANEOUS PROCESSING Direct attention and decrease extraneous processing	Coherence Add only related material (audio or graphic)	Make information clear without embellishments	Frascara, 2015
		Isotype method everything should be meaningful in their illustrations.	Neurath, 1936
		Relevance Principle "Include in one chunk, only information that relates to one main point based on that information's purpose or function for the reader".	Horn, 1989
	Signalling Highlight essential material	**Typography differentiation** (weight, slope, expansion (height and width), curvature, connectivity, orientation, regularity, size, colour, upper and lower case, letterspacing)	Frascara, 2015; van Leeuwen, 2006; Waller, 1991;
		Type hierarchy use of different **typographic styles**	Waller, 1991;
		Space structured text or lists to arrange text, show hierarchy and convey meaning	Hartley, 1994; Twyman, 1981; Waller, 1991
		Visual hierarchy use of size, shape, texture, directionality, depth, movement, colour or luminescence to achieve differentiation and grab attention	Bertin, 2011; Twyman, 1985; Peters, 2014
		Pointed words such as because, so, then, first, etc. for 'easyfication' of the text and **content structure** such as introductions and conclusions, content lists, etc.	Horn, 1989; Waller, 2011
	Redundancy Spoken and written text	----	-
	Spatial Contiguity Position related text and graphic, and words and graphics near to each other	**Gestalt principles** continuation, proximity, similarity, closure, and figure strengths	Koffka, 1935/50; Peters, 2014;
		Use of **labels** and **captions** based on Gestalt principles	Peters, 2014
		Graphics and running text composition	Kress & Van Leeuwen 2006; Hartley, 1994
	Temporal Contiguity Narration and graphics together	----	-
	Simplification Reduce visual elements, careful that children have difficulties with abstract concepts	**Thoughtful reduction** or minimalism, taking the unnecessary things out	Carroll, 1990; Peters, 2014
		Use of **pictograms** and **simple representations** (line drawings, silhouettes)	Frascara, 2015; Peters, 2014
		Isotype principles usage of clear and simple graphics	Neurath, 1936
		Hide make things not visible at first (use of hover, **layers**, etc.)	Peters, 2014
MANAGE ESSENTIAL PROCESSING Reduce content complexity understanding mind limited capacity	Multimedia Include words and graphics rather than only words	**Visualisations** images can summarise much information	Tufte, 1990
		Isotype principles visual education could enhance learning and teaching in schools. Usage of many used many different methods of visual representation	Burke, Kindel and Walker, 2013
		Different type of graphics representational, relational, organisers, transitional, to place learning in context, to show things that otherwise are invisible	Hartley, 1994; Peters, 2014; Twyman, 1985
	Modality Use audio rather than on-screen text	----	-
	Pre-training Key concepts and vocabulary first	----	-
	Segmenting Break a continuous lesson or material into manageable segments	Use of **chunks** and **blocks of information** Chunks are small and processable pieces of information and blocks is information laid out in a consistent way.	Horn, 1989; Murray, 2012
		Sequencing and **segmenting** to avoid introducing all the information at once	Norman & Spohrer, 1996; Peters, 2014
		Interactive layers use of layers to access to more information	Peters, 2014; Garrett, 2011
	Limited short memory Organize information to stay within memory limits	Use of **chunks** and **blocks of information** Chunks are small and processable pieces of information and blocks is information laid out in a consistent way.	Horn, 1989; Murray, 2012
		Use of **repetition** in text and **structure content** with **summaries**, key-facts, etc.	Horn, 1989; Peters, 2014; Waller 1991
FOSTER GENERATIVE PROCESSING help knowledge integration by engaging learners	Personalization User conversational style	----	-
	Voice Use human voice	----	-
	Embodiment Human like characters	----	-
	Image No need for a visual character	----	-
	Storytelling Use storytelling	Narration	Wendel, 2014
		Narrative representations graphics, storyboards, movies, animations, etc.	Kress & van Leeuwen, 2006; Twyman, 1985
	Learner control Promote self pacing control	Include noticeable **controls** to navigate the content, allowing the user to control his **time** with the information.	Peters, 2014
	Prior-Knowledge activation Activate prior knowledge first.	----	-
	Dynamic visualisation	----	-
	Aesthetic-usability aesthetically pleasant for your learner	**User-centred design** know your user to know what he likes by applying user research methods.	Garrett, 2011; Norman, 1990
		Harmony and **proportion** design elements fitting well together	Pettersson, 2002; Norman, 1990

2.5 Information design in e-learning design

The design of e-learning environments for children is a multidisciplinary task where the design of the content to support instruction is crucial. In this literature review, it is revealed that designer can have an active role in designing for instruction. Particularly, Kazmierczak (2002) emphasises the role of designers in presenting scientific information:

> "... people trained and experienced in form development and familiar with visual perception should be the ones who translate scientific structures into comprehensive visual models." (p. 186)

Designers frequently make use of research from other disciplines to aid their decision making. Handling users' characteristics, the implications of teaching science for children, and the strategies to support knowledge integration, designers can contribute to the learning experience. This shows the inherently multidisciplinary nature of design (Waller, 2011).

Particularly, information design is linked with the design of instructional materials. The goal of informations design was discussed by many author. The following is just one example:

> "Information design aims at the creation of effective communications through the facilitation of the processes of perception, reading, comprehension, memorization and use of the information presented." (Frascara, 2015, p. 5)

The aim of information design provided by Frascara seems to be aligned with the goals of multimedia learning to facilitate knowledge integration:

- Minimise extraneous processing (facilitation of the process of perception)
- Manage essential processing (facilitation of the process of comprehension and memorization)
- Foster generative processing (integration to memory and effective communication)

In this context, seems interesting to explore and analyse how designers can aid multimedia learning aims. Information designers had developed through practice and research some techniques that can help to implement those learning sciences' strategies. Table 5, identifies many commonly used design methods that can be used to reach the strategies proposed. It shows the instructional goal, the learning principles and strategies proposed by the learning sciences and then possible design techniques supported by some authors in the design field to achieve the strategies.

Chapter 3 Research Methods

The current chapter tries to fulfil the third research aim:

2. *Construct* a framework for analysing an e-learning environment

The framework will also try to contribute to answering the research questions:

- How Science concepts are presented in an e-learning environment like EDUCiencias?
- What considerations should designers take into account to enhance learning?

3.1 Research strategy

The aim of the research is to see what designers can do to enhance learning. To this end, strategies to support information were identified in the previous chapter, which are invaluable outputs for designers as they summarise evidence-based advice from the learning sciences in how to support information. Furthermore, it is important to see how these strategies could be translated into design features.

A case study is the methodological approach for this dissertation. Applying a case study will contribute to see the strategies translated and implemented in a particular context. The strategies listed in Table 4 *Principles and strategies to enhance learning* are the ones to seek, but they are just separate pieces of advice. There is evidence that each of them is beneficial individually, but there is no clear proof of how many of them must be used or when each of them is suitable for a project. A case study will help to see the strategies applied in a real example.

The case study is an e-learning software; the analysis of it would be based on the observation of its screens. To guide the observation and analysis of these screens, a methodological approach is mandatory. An analytical framework would direct the analysis to identifying design methods are applied that improve learning. The framework will try to guide and organise the observation and analysis of the case study.

3.2 Case study selection

EDUciencias is an educational product created in Uruguay for Uruguayan primary school students. It was conceived as a product to support primary science curriculum in school-aged children at fifth and sixth-grade, that is for 10 to 12 years old children.

This product was selected for several reasons. First, this product was picked because EDUciencias coincided with the selected criterion. It is an e-learning environment for primary school children to learn science. Matching perfectly the criteria as it also intended to be used in the classroom in a blended learning modality.

Second, because this is a product developed for Plan Ceibal, a national organisation that applied the One Laptop per Child scheme in Uruguay; for the first time in a whole country with free access for all students in public education (EDU Editorial, 2016). This means that all school-aged children in the country will have access to this product on their computer. Hence, the impact of it is potentially huge.

The third reason is that it is a product conceived by a multidisciplinary team. What, as seen in the Chapter 2 Literature Review, it is desirable for the development of educational products. In the team, there were designers, developers, and educators involved (EDU Editorial, 2016).

The final reason is that after contacting the developers, they offered full access to the product, what it is not easy to find in licenced educational products. Their collaborative attitude and accessibility are also an advantage to work on this case study.

One particular product of EDUciencias will be analysed. There are two versions of the product, one for the teachers and other for pupils. This case study is based on the students' version, as the focus is to assist learners rather than teaching. Also, there are two smartbooks developed, one for fifth-grade and other for sixth-grade. The analysis will be of the one for sixth-grade, as this is the one that it has been emulated for Windows especially for this project. Otherwise, a computer from Plan Ceibal with Sugar operative system is needed to run the books; that was impossible to access for the timing of this dissertation.

3.3 Analytical framework

The framework for analysis has a particular emphasis in the analysis of the strategies to support information, but before that it is important to understand the context of the product and where within the product the information is provided. The framework will look into three things:

- Context and type of product (strategy)
- Product to assist science teaching (structure)
- Strategies to support instruction (delivery of information)

Context and type of product

First, it is important to understand the context of the product. Who and when the product was developed and to which educational theories it subscribes. It is also crucial to now who is going to use it the product. Knowing the characteristics of the users will help to analyse the software from a user-centred approach.

Then, it is important to know what kind of product it is. What are the educational objectives, and how and where it is supposed to be used. As seen in chapter one

Table 6 Matrix for analysis by strategies applied

Goal	Principle	Application on micro level	Application on macro level	Application on meta level
MINIMIZE EXTRANEOUS PROCESSING	**Coherence**			
	Signalling			
	Redundancy			
	Spatial Contiguity			
	Temporal Contiguity			
	Simplification			
MANAGE ESSENTIAL PROCESSING	**Multimedia**			
	Modality			
	Pre-training			
	Segmenting			
	Limited short memory			
FOSTER GENERATIVE PROCESSING	**Personalization**			
	Voice			
	Embodiment			
	Image			
	Storytelling			
	Learner control			
	Prior-Knowledge activation			
	Dynamic visualisation			
	Aesthetic-usability			

e-learning is a versatile medium. This part of the analysis is the only one reached by researching materials provided by the developer and others, and not in observation as the other two parts.

Product to assist primary science teaching

This analysis will look into the structure of the product, and how that is related with the framework of how children learn science, introduced in Chapter one Literature Review.

At this level it is relevant to inspect the:

- Product structure (information flow and architecture)
- Design maxims (patterns or style sheets)
- Content structure (Elements and distribution)
- Access structure (navigation of the product)

Different methods will be used to analyse the elements listed above. First, the structure of the product will be analysed by a screen flow diagram, and it will reveal the structure of the product and how the user can move within it. Second, an overlook of all the screens will lead to a graphic comparison to find patterns and stylesheets (Gillieson, 2008). Third, the content of the structure will be analysed; firstly by categorising the different types of elements used for instruction. Then, the relation of these elements will be studied by looking into their granularity and density (Gillieson, 2008). Also, the page layout will be analysed to find the grid system which will reveal the way in which content is structured (Garrett, 2003). Finally, the navigation of the product will suffer a visual analysis revealing the access structure; these are cues that help the users know where they are and how to move through the book (Waller, 1985).

Strategies to support instruction

This part of the analysis will look directly to the instructional content. It will attempt to identify the principles and strategies proposed by the learning sciences and how are these strategies recognised in the product itself through its design. Table 5 *Strategies to enhance learning supported by design techniques* already introduced some techniques used for these purposes.

The critical analysis will try to identify the use of these strategies on a micro, macro and meta level. The micro level is related to the components of the design, while the macro level is the content structure, this means the relationship between the components. Finally, the meta level describes the principles behind the design (Gillieson, 2008). To do so, the matrix for analysis in Table 6 is going to be applied. The matrix intends to contrast the findings with what was discovered in the literature review.

Altogether, the analysis will look into the context the product, the structure of it, and finally how the strategies proposed by the learning science are traduced intro design at different levels.

3.4 Limitations and potential problems

Despite the framework was designed for systematic analysis and looks into different levels of the product, it mainly examines the formal attributes of the product and not the performance of it. This means that even detecting the strategies used the product they can be effective or not. To determine the effectiveness, further analysis will be needed. It is also important to clarify that a particular number of strategies applied is also not necessarily related to the efficiency or success of the product.

Chapter 4 Case Study: findings and discussion

In this chapter, the result of the case study will be revealed applying the three-stage method presented in Chapter 3 Research methods. The aim of the chapter is to contribute to the third research objective.

3. *Analyse* and *outline* some of the design considerations for enhancing learning in EDUCiencias.

EDUciencias' smartbook will be described, analysed, and evaluated. First, the product will be described and put into context. Then, the structure of it will be analysed in relation with how children learn science; and next, a matrix will be used to identify e-learning strategies on the content on a micro, macro and meta levels, and the results will be discussed. To sum up, at the end of the chapter there is a synthesis of the findings.

The analysis is based mainly on the observation of the product screens. Screenshots of the path of a user from the home page through a unit are shown in Appendix A.

4.1 Discussion of context and type of product

Context

The product was developed by EDU Editorial an Uruguayan enterprise for Plan Ceibal. In 2014 the first product was created for fifth-grade and in 2015 for sixth-grade, they both can continuously be improved by the team with feedback provided online through the product, as once connected to the internet it sends information about when and who used it (EDU Editorial, 2016). This means that it is a dynamic product; this is a desirable situation, as it can be linked with the spiral design methodology where products are in a continuous loop of evaluation and improvement (Wendel, 2014). Additionally, teachers can report children's attitude towards the book as EDU Editorial regularly visits schools where the smartbook is used to evaluate it (EDU Editorial, 2016). These visits are opportunities that possibly they use, or can use, to do usability research with kids as Druin (1999) suggests.

The product integrates the Constructivist model, as most of the e-learning environments do (Clark & Mayer, 2011; Mason & Rennie, 2006; Peters, 2014) and tries to improve in an educational cognitive, and social level. This can be reflected in the

constant calls for reflection, group activities proposed, and the tasks recommended to apply the new knowledge in their communities.

They also claim to try to boost scientific attitudes by using teaching sequences. These sequences involve experimentation, the arousal of curiosity and prior knowledge, lectures to introduce theoretical contents, exercises that increase in difficulty to apply the knowledge, and finally, tasks to use the knowledge in a new context (EDU Editorial, 2016). These would be seen in detail with the analysis of the structure of the product.

The product is designed to be used in a sixth-grade classroom, and it does not need an internet connection, which prevents any problem with connectivity, ensuring uninterrupted use of the book. An e-learning product utilised in the classroom, as seen in the literature review, is considered as a blended modality. This means that the interactions experienced with other students and the teacher are not through the computer, providing the possibility to do for example introductions, add more material and give personal feedback to the pupils face-to-face.

The users of the product are children in sixth-grade (10 to 12 years old children) in Uruguay's public primary schools. In 2015, there were more than 42,000 children in this grade from different social and economic backgrounds- this number includes rural and urban schools (ANEP, 2016). It is expected that at this grade the children would have reached the level of autonomous reading and writing, and they are in Piaget's Concreate Operational Stage which means that they can apply logic to concrete things, but not abstract ones (as cited in Peters, 2014).

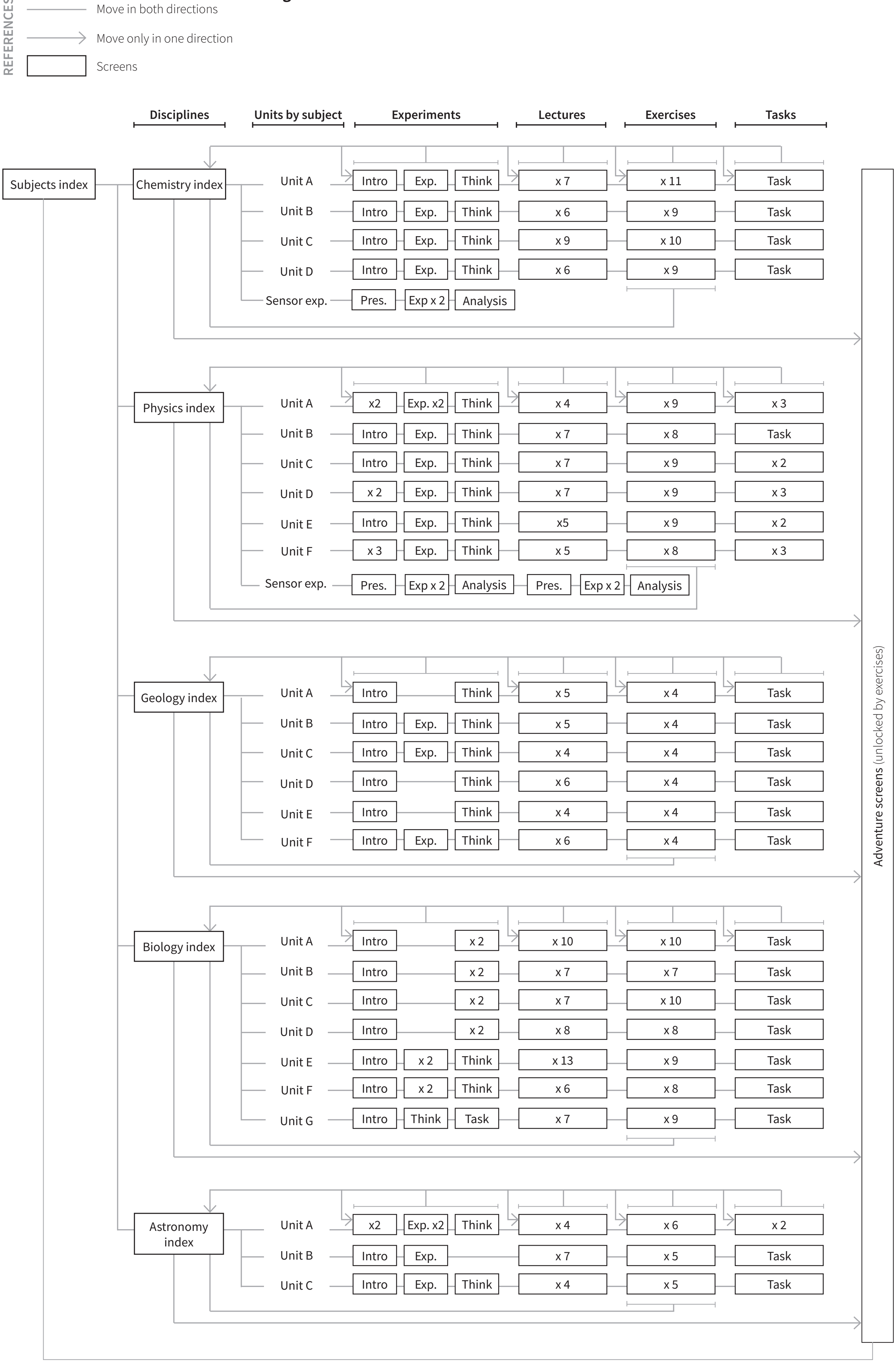
Type of product

EDU Editorial, the creator, defines EDUciencias as 'smartbooks'. They are similar to books but with more graphics than traditional curricular classroom books, with exercises with increasing difficulty, in a digital format. EDU Editorial (2016) states that this format was chosen on account of, nowadays, books are still the most used tool in the classroom. Thus, using smartbooks is a way of gradually introduce technology in the classroom in a natural way.

The smartbooks, also called 'e-books', only run in the 'XOs' laptops specially provided by Plan Ceibal, with the 'Sugar' operating system (Plan Ceibal, 2014). The computers have a small display measuring 7.5" diagonally and a 1200×900 pixel resolution; this means that the display of information is challenging due to the limited space.

All the findings presented in this stage are a valuable input to analyse in context the structure of the product and the enhancing strategies applied. They also verify that the product chosen is adequate as it has a constructivist approach, and it is designed to support instructions inside the school classroom.

Figure 3 Screen flow



4.2 Discussion of structure

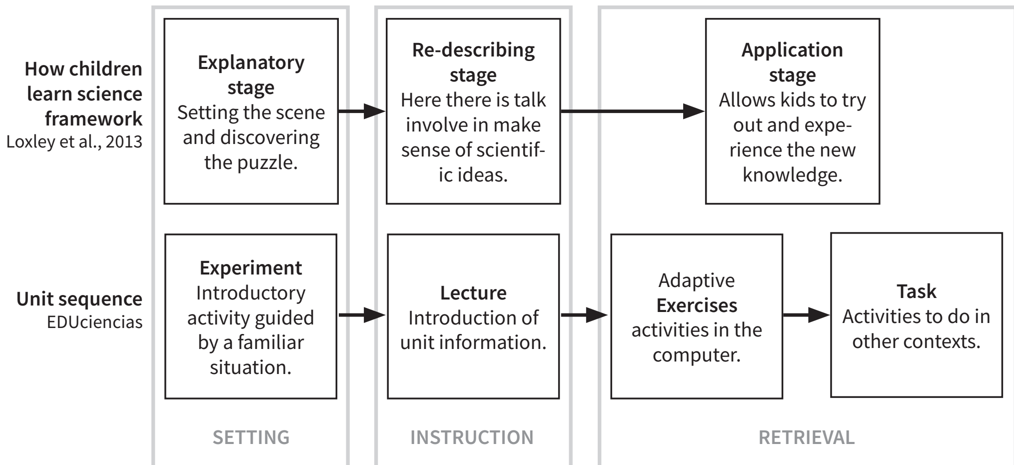
Product structure

The first method to analyse the structure of the product is the screen flow showed in Figure 3. The diagram reveals that the product is organised into five curricular disciplines (CEP, 2009), and inside each, there are different units. Exceptionally, two disciplines also include sensor experiments. Disciplines are accessible from the homepage, where there also is introductory information about the characters of the smartbook and the credits. The other leading part of the smartbook is the Adventure, a linear story experienced by the characters, which is unlocked by doing the exercises, and accessible from the discipline's index.

Each of the units is arranged in a pedagogical sequence. Firstly, there is an experiment or *activity* to trigger the curiosity and retrieve their prior knowledge, guided by a familiar situation experienced by the characters. Secondly, there is a *lecture*, to make sense of scientific ideas involved. Thirdly, there are various *exercises* which are presented in a progressive difficulty. Finally, there are one or more *tasks* to apply the knowledge in a different context, usually outside the school.

Specifically, in the lectures, there is a linear sequence, where learners can move just forwards and backwards between the different screens. The lectures have between four and 13 screens. Within the unit, children can always go to the beginning of the lecture. Moreover, the sequence of the units is similar to the framework seen in the literature review. Figure 4 shows the parallelism between the framework and the units' structure. This demonstrates that the structure of the EDUciencias supports the framework for learning science and should be adequate for children learning sciences.

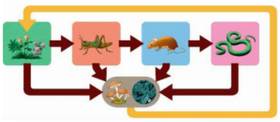
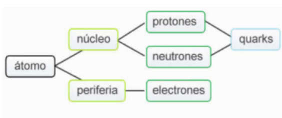
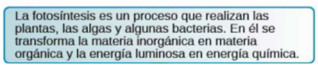
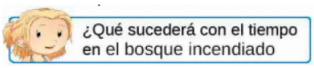
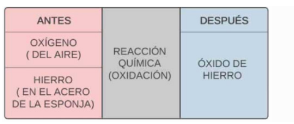
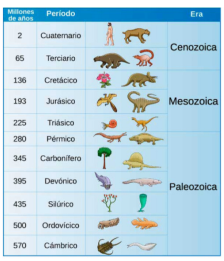
Figure 4 Units structure and framework for teaching children science



Design maxims

There are four different patterns of screens (see Figure 5, next spread). The lecture has pattern D that includes a white background with text and sometimes images that would be analysed deeper in the next section.

Table 7 Elements

Purpose	Type	Variations	Example
DISPLAY CONTENT	**Text block**	Paragraphs	¿Qué sucede en el interior de nuestro planeta? A partir de la década del sesenta, los esfuerzos por conocer la naturaleza de los fondos oceánicos produjeron avances sobre el funcionamiento de la Tierra. Así, se formuló la Teoría de Tectónica de Placas. Esta sostiene que la capa externa y sólida de la Tierra (Litósfera) se divide en un conjunto de doce a quince placas que flotan y se desplazan sobre material menos rígido y más caliente (Astenósfera). Pueden estar constituidas por diferentes clases de rocas que componen las cortezas. Hay dos grandes tipos de corteza, y las placas pueden estar formadas por uno o por ambos. La **continental** es de composición granítica, menos densa y más espesa. La **oceánica** es de composición basáltica, más densa y más delgada. Esta teoría explica cómo se forman las montañas, cómo nacen los océanos, por qué y dónde ocurren los terremotos. Además, brinda una guía para la búsqueda de recursos minerales e hidrocarburos.
		Lists	▪ Se disparan neutrones contra los átomos de uranio, que se vuelven mucho más inestables. Estos se fisionan y originan núcleos más pequeños y algunos neutrones. ▪ En el lugar de la masa que desaparece, surge energía radiante: los rayos gamma, las radiaciones de más alta energía. ▪ Los neutrones originados por la fisión se disparan hacia otros átomos de uranio: si los alcanzan, el fenómeno se repite ¡por partida triple!
	Images	Illustration or photography	
		No background	
		Images with text	
	Diagrams	Only images	
		Only text	
		Mixed	
	Boxes	Only text	
		Text and images	
	Tables	Only text	
		Text and Images	
NAVIGATION	**Labels**		

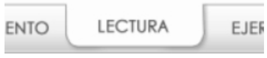
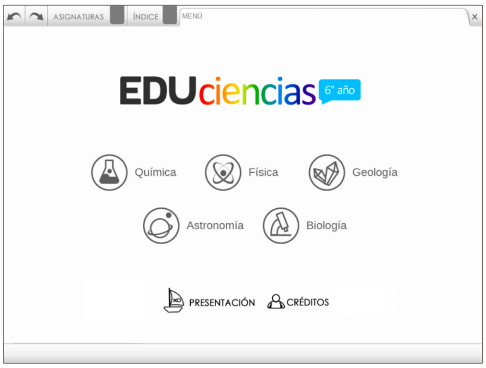
Purpose	Type	Variations	Example
	Tabs		
	Buttons	Text	
		Icons	

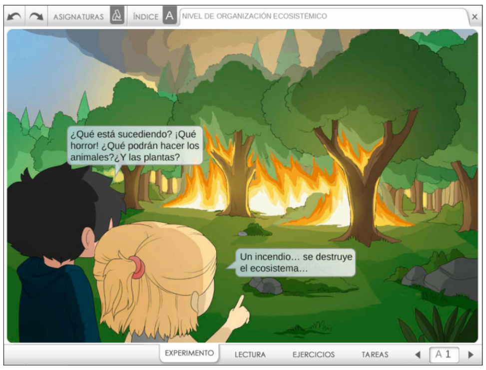
Figure 5 Style screens

Pattern A - *Home*

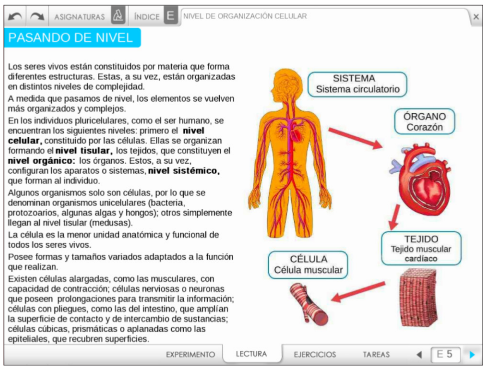


Pattern B - *Index*

Pattern C - *Characters illustrations*



Pattern D - *Unit*



Pattern D is used for most of the screens. There is no differentiation in the style for activities, experiments, lectures or tasks; this could be seen as a drawback, but on the contrary, this could help to avoid predisposing the kid to a passive mode and maintain the engagement throughout the unit. Nevertheless, there are other cues that signpost in which part of the unit the learner currently is, this is discussed in the access structure analysis section.

Content structure

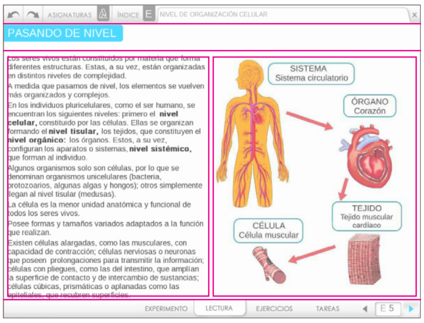
Table 7 visualises the different types of elements that are in the eBook, and they are classified in terms of their purpose: the ones used for presenting information and the ones used to define the navigation.

The elements used to present information employ different modes of representation. As seen in the theory, scientific concepts are based on a multimodal discourse, and this is reflected in the various representational modes used. Moreover, each type of element uses more than one mode of representation: words, images, symbols and graphic positioning.

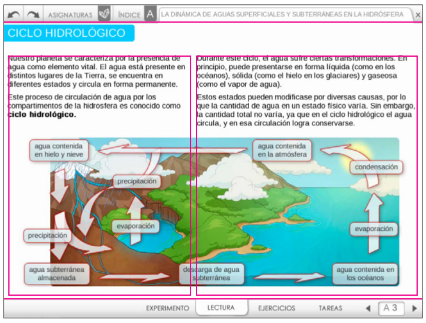
However, all the elements use only graphic modalities; there is no use of sound or movement to convey meaning. It seems obvious the decision to avoid sound, as the product is used by many children in the same room, where sounds reproduced uncoordinatedly can be very distracting. The reason why no animations are used is not clear at this stage of the analysis. It could be related to technical issues or logistics, but withal in theory animations could be beneficial to introduce and clarify some concepts especially for complex processes.

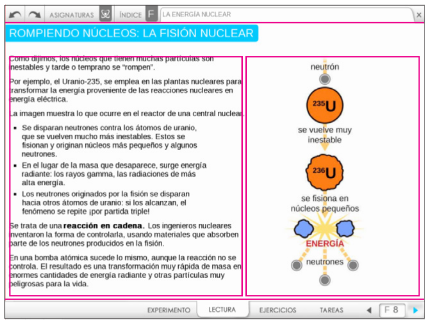
Figure 7 Layout structure

Two symmetric columns with gutter

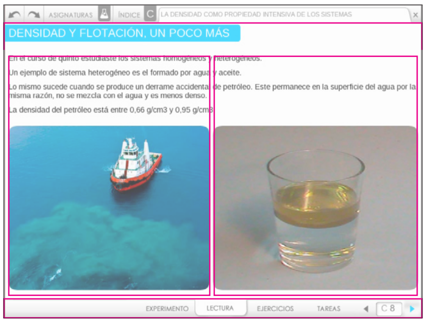


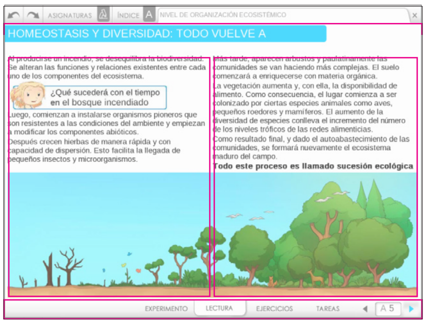
Two asymmetric columns with gutter



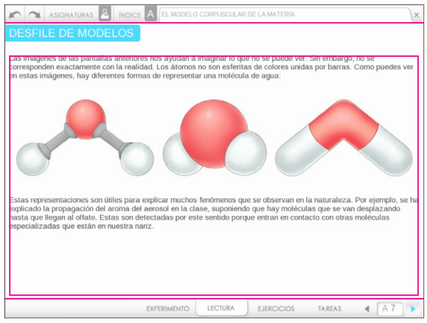


Two symmetric columns with gutter mixed with one column

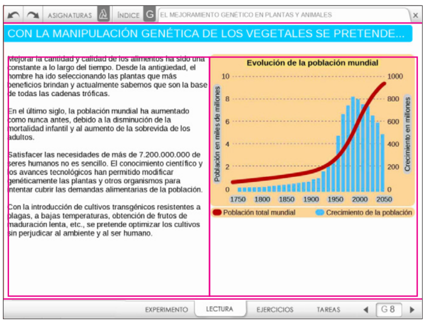




One column



Two column no gutter



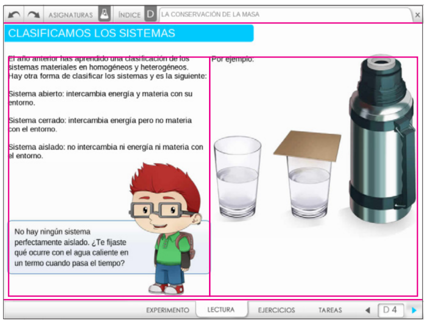
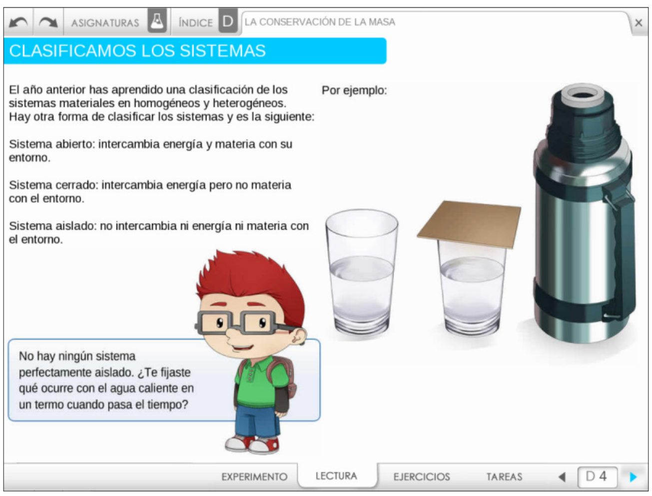
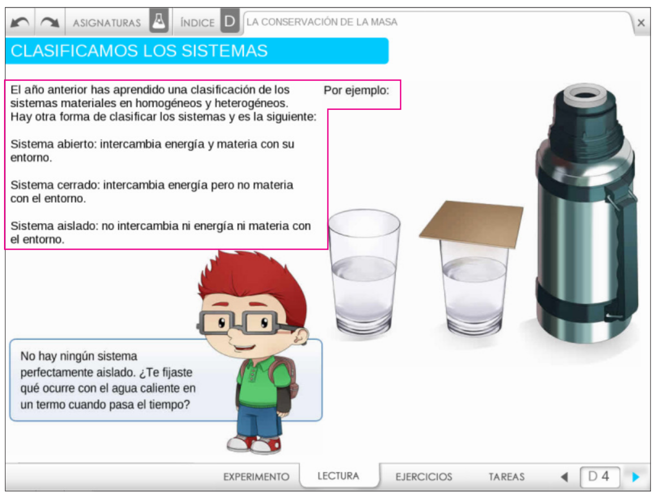


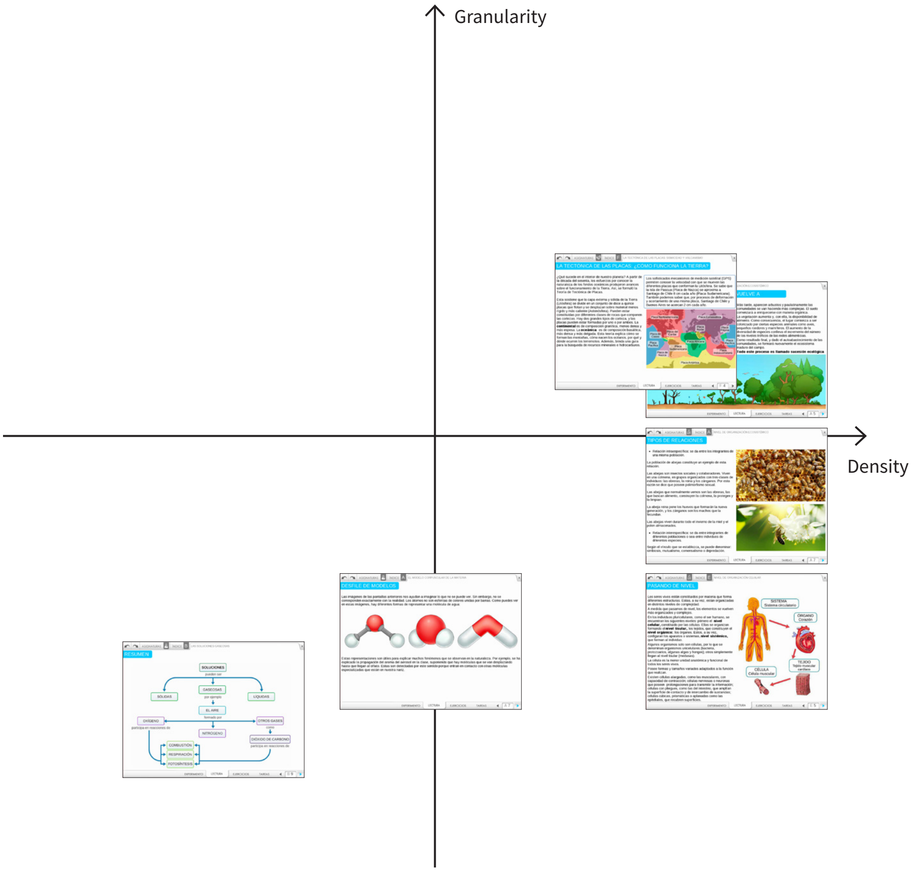
Figure 8 clusters





Granularity and density are used to evaluate the elements' distribution on screen. Granularity refers to the sizes of graphic clusters on-screen, and density is related to the amount of them about the screen space (Gillieson, 2008). Figure 6 shows the relation between these two variables in Style Screen D, the one that supports the lectures. Generally, content screens are dense, but they do not have many elements, what is beneficial regarding focus and retention. A high density with few elements could be due to the small screen. What is relevant is to detect if such density is perceived as too much information encumbering the learner's extraneous processing as Mayer (2014) suggests.

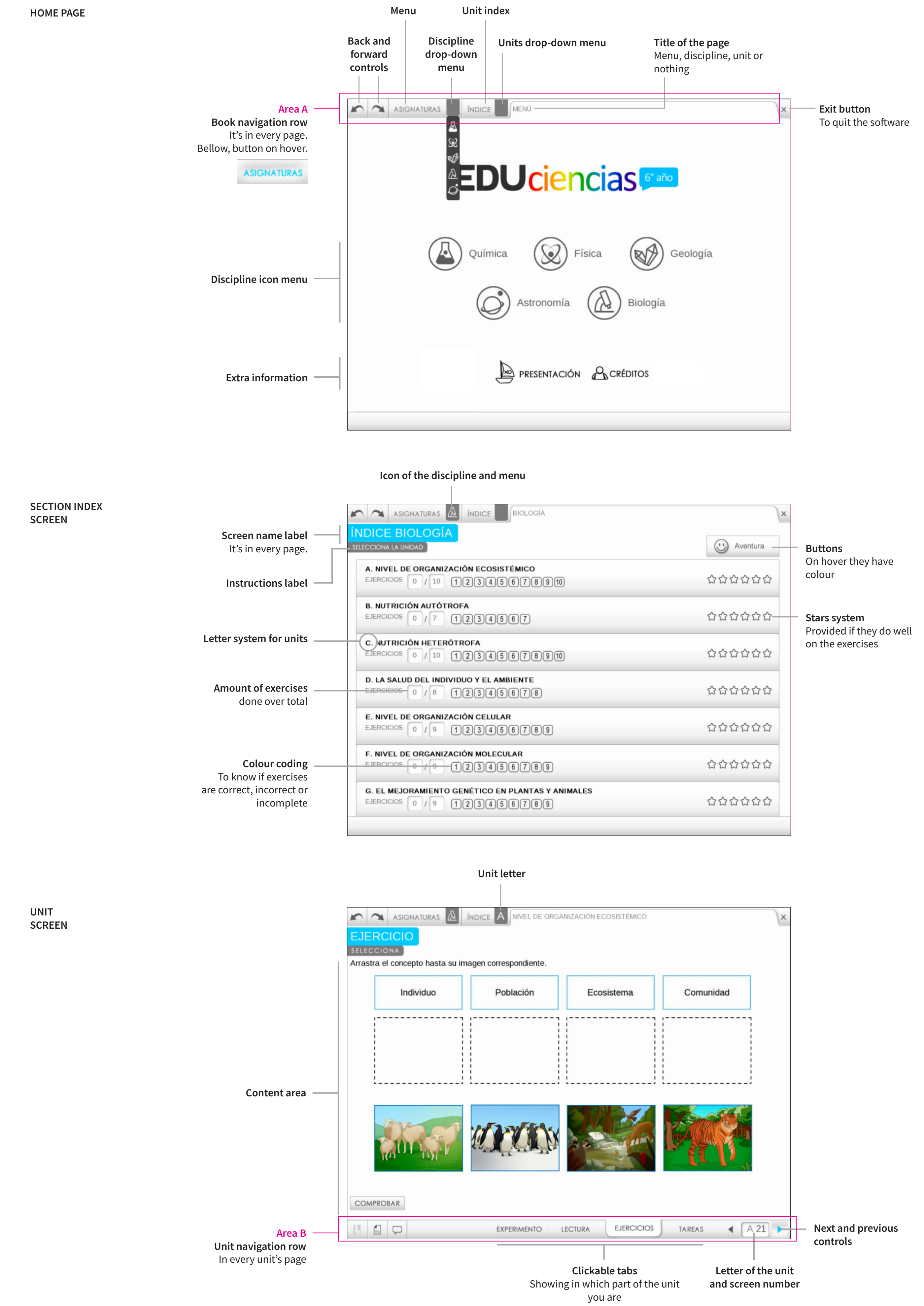
Figure 6 Granularity vs. Density



The structure and flow of the content are generally organised by a grid; a technique borrowed from printing that guarantees uniformity (Garrett, 2003). The use of grids for consistency helps to minimise the extraneous processing because the learners know what to expect. In this case, the content seems to be organised in a two column grid with slight margins and gutters, however, once analysed the two columns are flexible and modified to arrange the content on-screen, only the margins and titles are fixed (Figure 7).

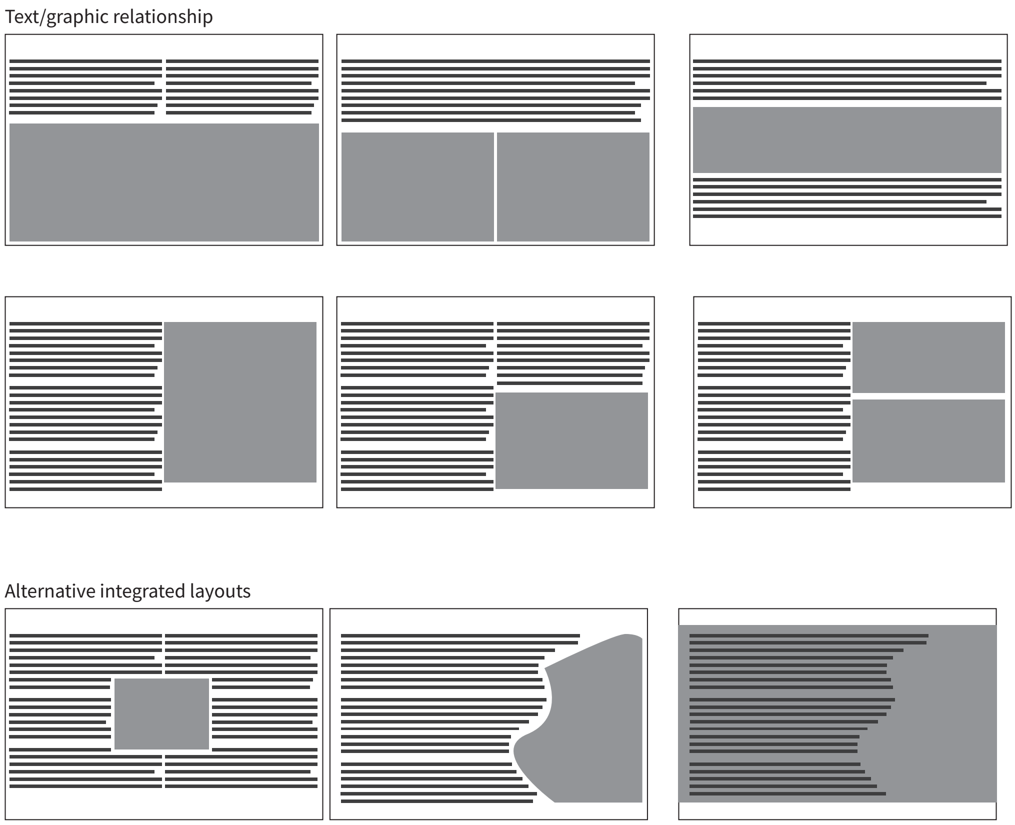
The small screen display seems to be the major constraint. To fit the desired content on the screen, small margins are used. However, small margins can lead to a sensation that it is too full or dense. The short gutter has the same implications that the margins, besides, it can result in problems on the cluster of information, as it shown in Figure 8, where information can be directly related to the paragraph rather than the graphics.

Figure 10 Access structure analysis



Despite the grid's absence, the layout system always structures the information in only one or two columns. The single column works appropriately for graphics or images but when used for paragraphs results on lines of text considered too long, with more than 100 characters (Peters, 2014). When two columns are used, paragraphs are divided into columns or one column is used for text and the other for graphics. The relation between text and graphics is generally adjacent to each other or intercalated. There is no overlapping or integrated text, what results in visual blocks of information as Figure 9 shows.

Figure 9 Text/graphic relationships



Access structure

There are three different screen patterns for navigation all with different requirements. The three of them are analysed in Figure 10:

There are two main navigation areas graphically differentiated from the content. In all of the screens, there is a row at the top (*Area A*) of the screen with options to navigate the book; this also gives information about in which discipline and unit the user is currently in. The other one is a bottom row (*Area B*) where children can navigate within the unit through tabs and arrows.

Both areas give control over the learning experience to the user, promoting self-pacing. This is one of the strategies that the cognitive sciences propose. However, as seen in the flow of the page, this control is limited, as the lesson has only the possibility to navigate it in a linear way. This is also aligned with the idea that novice learners need more guidance when faced with the information.

Table 8 Strategies to minimise extraneous processing applied

Goal	Principle	Application on micro level	Application in macro level	Application in meta level
MINIMISE EXTRANEOUS PROCESSING	**Coherence** Add only related material			**Relevance principle** All the material is related to the lecture. Sometimes the characters appear to introduce reflections or to emphasise and the adventure is clearly separated from the lecture.
	Signalling Highlight essential material	**Typography differentiation** used of bold for highlighting in-text (not in all the screens or units) **Visual hierarchy** used of colours and shapes for diagrams and tables	**Type hierarchy** use of different styles for labels and text (not enough differentiation between text and labels or captions sometimes) (not consistent the styles for labels and captions) **Visual hierarchy** used of boxes, diagrams or tables **Space structured text** use of lists **Content structure** some units include a summary	Use of **access structure** to show the learner where he is
	Redundancy No spoken and written text simultaneously		no use of audio	
	Spatial Contiguity Position related text and graphic, and words and graphics near to each other	**Diagrams labels** are always used near the parts labelled, linked by a short line or over the diagram. **Diagrams** and tables make use of gestalt rules to convey meaning.	**Captions** they are underneath the graphic (but could benefit from better proximity in some cases) **Relation text and graphics** in general there is one picture per screen, generally the images are in a column or behind the text along the two columns. **Gestalt** use of columns (could benefit from bigger margins and gutter)	
	Temporal Contiguity Narration and graphics simultaneously		no use of audio or videos	
	Simplification Reduce visual elements	Use of simple forms and few colours for diagrams. (Less variant could be used for labels -colour, filling, outline, shadow-). Simplification in diagrams and images by **eliminating the background** or unnecessary information. Most of the representations are pictorial representations. (Linear representations could be used)	No many visual elements per page. No use of layers or interactivity to hide info.	

Also, further information is provided about where and in which unit the learner is. For this purpose, a representational iconography for the subjects is introduced in the homepage, and then units are identified in the subject's index by using letters. Both codes, as well as the rest of the iconography implemented, could be simply understood by the children as they use familiar elements for children as Druin (1999) suggests. EDUciencias also follows her suggestion with buttons with a skeuomorphic treatment supported by humans' facility to detect depth (Peters, 2014). The letter coding for recognising the unit also enforces the idea of progression.

There are other aids provided. Like the *title label* present in most of the screens, except the home and the characters illustrations pattern, and the *instruction label* used in some screens where the students are asked to do something. These are significant features to signpost the smartbook helping learners to orientate and find what they are looking for easily (Waller, 1985). This could be seen as an extension of the application of the signalling principle to help the learner find the desired information (Mayer, 2014).

Overall, the analysis of the structure revealed the importance of the structure in relation to the framework for learning sciences, the multimodality of its elements and the use of design to enhance learning by guiding the learner with the layout. This analysis would also be useful in the next section, to study the lessons as a part of the smartbook system.

4.3 Discussion of strategies to support instruction

The Table 4 *Matrix for analysis by strategies applied* introduced in the last chapter Research Methods was applied to EDUciencias for sixth-grade. It is important to clarify that this analysis is not about the successfulness of their application, but only for checking if strategies are used or not; however, there are some reflections regarding their implementation. To organise the discussion on this level, it will be divided into the three e-learning goals; maximise extraneous processing, manage essential processing and foster generative processing.

Application of design techniques to minimise extraneous processing

The first goal is related to directing the attention to the relevant information; this is stretchy related to the design of on-screen information. On this basis, it is appreciated in Table 8 that most of the design interventions to support the strategies are applied on a micro and macro level. For instance, on a micro level this are the techniques identified (see Figure 11, next page):

- Typography differentiation and visual hierarchy for signalling
- Labelling and gestalt rules in diagrams to convey spatial contiguity
- Elimination of backgrounds to simplify graphics (seen in the analysis of elements in the previous section)

On a macro level (see Figure 12, next page):

- Typography hierarchy, visual hierarchy, and space structured text for signalling.

Figure 11 Examples of application of design techniques to minimise extraneous processing at micro level

For signalling

Typography differentiation

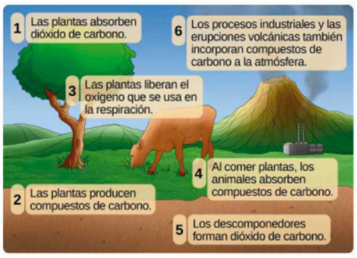
Corresponde a los animales cuyo alimento es de origen vegetal. Pueden ser frugívoros y comer frutas, folívoros y comer hojas o **granívoros** y comer granos. Pueden producir efectos positivos en la planta pero también negativos, ya que cuando comen las flores, disminuyen la posibilidad de reproducción.

Visual hierarchy

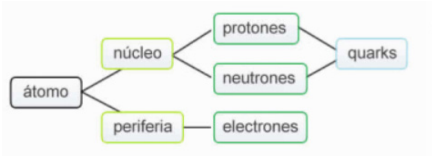
ANTES		DESPUÉS
OXÍGENO (DEL AIRE)	REACCIÓN QUÍMICA (OXIDACIÓN)	ÓXIDO DE HIERRO
HIERRO (EN EL ACERO DE LA ESPONJA)		

Spacial contiguity

Labels next to parts named



Gestalt rules



Simplification

Elimination of background

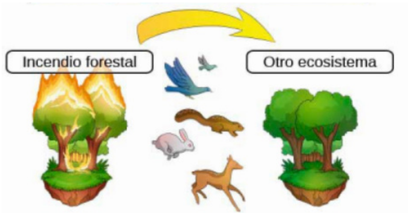


Figure 11 Examples of application of design techniques to minimise extraneous processing at micro level

For signalling

Typography hierarchy

Titles EN LAS HOJAS OCURREN

Paragraph La hoja es un órgano formado por varios tejidos:

Character Recuerdo que por medio de los estomas se intercambian gases.

Labels Base

Visual hierarchy

Cuando observamos en los troncos de los árboles, en la superficie de las rocas o cuando vamos al campo y en los alambrados hay organismos como los de las imágenes. ¿Piensas que son plantas?

Los líquenes sobreviven a condiciones muy extremas. Son marcadores de contaminación atmosférica. Son muy abundantes cuando el aire no está contaminado.

Space structured text

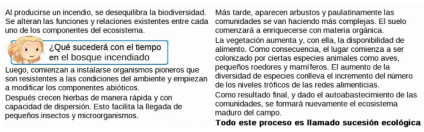
La hoja es un órgano formado por varios tejidos:

- El tejido epidérmico le brinda protección y a su vez le permite relacionarse con el ambiente, intercambiando gases (oxígeno y dióxido de carbono) y eliminando vapor de agua (proceso de transpiración) a través de los estomas.
- El xilema y el floema se ubican en las nervaduras y conducen savia bruta y savia elaborada respectivamente.
- El parénquima de elaboración o clorofiliano permite a la planta captar la energía lumínica que proviene del Sol u otra fuente de luz y elaborar sustancia orgánica.

Spacial contiguity

Use of captions

Gestalt (columns)



- Use of captions, graphic/text relations (seen in Figure 8) and application of Gestalt rules to lead to spatial continuity.
- Use of few elements per page to achieve simplification (seen in elements distribution in the previous section).

On the other hand, on a meta level, the main strategy applied in EDUciencias is based on the Coherence principle. This principle states that all the material should be related to the instruction; this is shared by many information designers Frascara (2015), Horn (1989) and in the principles of Isotype (Neurath, 1936) for example. The material to be included might be a decision not exclusively of the designer; it is a strategic principle– that is the reason why it is applied on the meta level. Still, designers have the opportunity to check if this principle is being abided, and also they have to resist the temptation of adding extraneous engaging material to avoid cognitive overload during the processing. EDUciencias only includes material that is relevant to the subject.

There is only one strategy that is not applied on any level; that is based on the redundancy principle that warns about using written and audio words at the same time. However, in EDUciencias no audio is used.

During the analysis, it was detected that it is possible to improve the application of some of the principles such as signalling, contiguity and simplification. Signalling could be improved by using the current typography differentiation consistently in all the units. For example, right now some units make use of bold type for differentiation of key concepts, but it is not employed in all units. Regarding continuity, although it was used, on a macro level, some captions can be situated in closer proximity to the graphic. Also, a wider gutter could help to separate the two columns and improved cluster identification. Finally, some of the graphics could be represented with fewer details, as an example, there is documentation that people can easily recognise linear representations (Peters, 2014), this kind of treatments for some complex diagrams could be used helping to focus on the most relevant information.

To finalise the discussion on this level, it was found that 'good practices' in design, and from the 'practical wisdom' of designers are not mentioned by the cognitive sciences. However, a text designed for comfortable reading and the Consistency principle can contribute to minimise extraneous processing.

Designers had developed many techniques to set text in a way that would help readers to make less effort. There is plenty of research regarding legibility and readability from the design field. It demonstrates that the decisions made in the typography used or design and the setting of the text improve fluency and can make reading more comfortable; this way less cognitive resources are needed to read the text, and they can be used for understanding the message. There are many examples of this like the series *Typography Papers* done by Hyphen Press on many issues related to text design, legibility and fluency (Hyphen Press, 2016). Furthermore,

Table 9 Strategies to manage essential processing applied

Goal	Principle	Application on micro level	Application on macro level	Application on meta level
MANAGE ESSENTIAL PROCESSING	**Multimedia** Include words and graphics rather than only words	Most of the graphics are labelled or they have captions. Avoidance of abstract images.	Use of **different type of graphics** representational, relational, organizers, transitional.	Use of **visualizations** in almost every page photography, diagrams or illustrations.
	Modality Use audio rather than on-screen text		no use of audio or videos	
	Pre-training Introduce key concepts and specific vocabulary first			There is no specific introduction of key concept but before the lecture there is an ***introductory activity*** that gives this opportunity. The lecture generally start defining the most relevant concepts.
	Segmenting Break a continuous lesson into manageable segments		(No use of layers or interactivity to hide info.)	The lesson is break down in many **screens**, with few concepts in each.
	Limited short memory Organize information for memory limits	Diagrams and text introduce and have less than 7 **chunks**, or they are grouped accordingly		There is a **summary** at the end of some units (but not all)

there is specific research on how text layout can affect performance (Lonsdale, Dyson & Reynolds, 2006).

The other design contribution envisioned to help learners focus on the relevant material is the Consistency Principle that states that "For similar subject matters, use similar words, labels, format, organization and sequences" (Horn, 1989, p. 85). For example, if graphics are treated the same way, the language of a graphic is decoded just once and the next time the learner faces a graphic he already knows the language of it, and he can focus on the content. If there is no aesthetic or structural consistency, the learner needs to use extra cognitive processing. Consistency can be applied on many levels, from the organisation of the information, the structure of the content and in the elements itself. In this analysis it was revealed the consistency at a structure level, using stylesheets and grids, and on a micro level using the same kind of illustrations and typography throughout the smartbook.

Application of design techniques to manage essential processing

Table 9 shows how the case study applies techniques from the learning sciences to facilitate the processes of comprehension and memorization.

Just looking at the table it is possible to see that most of the strategies have been applied on a meta level. That means that the principles behind how to display the information are the major concern of the learning sciences.

Nonetheless, some of the strategies were applied on micro and macro levels. On a macro level, it was detected that different kinds of graphics were used to complement the text; and on a micro level, we can see that most of the graphics are labelled to secure the understanding of them. Also, it was found that micro level elements, generally, have less than seven parts, or they are grouped in chunks that are manageable for the short memory.

The paramount principle for enhancing e-learning is possible the Multimedia Principle, and it was applied on every level. Almost every page, except some summary screens, includes graphics. The different kinds of graphics used are relevant to the text. Furthermore, the graphics generally include pictures and words. The application of the multimedia principle on all levels shows the importance of multimodality in the product. It is also important to mention that the graphics used rely on representational images, as children are not mature enough to fully understand abstract concepts.

Some strategies could be implemented further. Segmenting, for example, was implemented only on a meta level by dividing the lecture into various screens. However, segmenting could be applied using clear layers of information to improve the accessibility to the information; these levels can be visual or interactive (Peters, 2014 and Waller, 2011). Summaries aid the memory but withal, they are only used in some of the units. By using summaries in every unit, the consistency principle is enhanced.

Table 9 Strategies to foster generative processing applied

Goal	Principle	Application on micro level	Application on macro level	Application on meta level
FOSTER GENERATIVE PROCESSING	**Personalization** Put words in conversation style and use polite speech	Texts are **directed to the children**.		The story uses **conversation** and dialogues. Some **dialogues** are added in the lectures.
	Voice Use human voice for audio narrations		no use of audio or videos	
	Embodiment Use human characteristics			Use of **human characters**, three kids school-aged as they are, and the Grandpa. There is also a dog.
	Image Not necessary to include a visual character			there are characters, but when they are not the text is still directed to them, like another anonymous character.
	Storytelling Use storytelling		.	**Trigger activity** guided by a familiar situation experienced by the characters. There is also a parallel **illustrated story** to engage the students
	Learner control Promote self pacing control in novice learners	Use of a**rrows, tabs and menus** to navigate through the smartbook		Learners can stay **as long as they want** in each screen.
	Prior-Knowledge activation Activate prior knowledge first	Use of **questions** to trigger reflection and **familiar situations**		All units starts with an **introductory activity** to think about the topic
	Dynamic visualisation State the function of the animation		no use of animations	
	Aesthetic-usability Make the content aesthetically pleasant for your learner	use of appealing and familiar illustrations (diagrams can be improved, harmony of labels) (typography aesthetics could be imrpoved)	Use of composition with clear white backgrounds (bigger margins) (more composition in the page, more flexible grid)	

Application of design techniques to foster generative processing

The last e-learning goal aims to engage and motivate the learner for knowledge integration. In Table 10 the different principles to foster generative processing in EDUciencias are evaluated.

All the strategies, except the ones that include audio or animations, are implemented in the product. Most of the principles namely personalisation, embodiment, image, storytelling, learner control, and prior knowledge are strategic principles and accordingly, applied on a meta level. Hence some were already examined with the structure of the product.

Personalisation, learner control and, prior-knowledge were also applied to the elements. The text directed to the children the way of personalisation used in EDUciencias on this level. Learner control principle is applied in the inclusion of clear controls to navigate the book; in this case with arrows, tabs and menus. Likewise the control, the strategy to activate what learners already know about the topic is used in the architecture of the lecture and a micro level with questions and calls for reflection. As seen ahead, giving control is important for constructivists because having control the learner becomes more active.

Aesthetics is difficult to evaluate, as its perception depends on the users. Therefore, to do it is necessary further testing by the users. However, some aspects that contribute with aesthetics can be evaluated, such as harmony and proportions (Pettersson, 2002). On a micro level, there is a notable selection of carefully done cartoon-style illustrations that seem to be appealing and familiar to Uruguayan students. However, there are also other styles of illustrations and images. On a macro level, the composition of the screen with a balanced use of colour on a clear white background is harmonic. Yet, a flexible grid with bigger margins could help to the overall aesthetics; making a less crowded screen to positively predispose the learner. Typography wise, the use of appealing typefaces and typesetting with clear typography hierarchy could be improved with more consistency throughout the lessons influencing positively users' impressions (Larson & Picard, 2005).

For making an aesthetically appealing and hence engaging product, designers rely on a user-centred approach and tacit knowledge about the concept of aesthetics. In user-centred design, designers use many research methods to get to know the user, and ultimately they also test the design (Frascara, 2015). Regarding the understanding of aesthetics, designers developed a sensibility where all the techniques used by design are used to reach a pleasant balance (Moggridge, 2007).

4.4 Synthesis of findings

After applying the analytical framework and discussing the findings, this section attempts to summarise the most important ones.

From the first part of the analysis, context and type of product, there are no particular findings, but the information gathered was a necessary input for the rest of the analysis. Particularly, in this part, it is discovered the blended nature of the product that explains why no audio is included in the lessons.

The second part revealed the relevant and close relation between the architecture of the product with how children learn science. The product is organised in the curricular disciplines proposed by the national science curricula. Within the disciplines, there are units, which are organised in a pedagogical sequence. The sequence first arises the curiosity and children's prior knowledge; then exposes the scientific concepts. Afterwards, it gives them opportunities to apply the knowledge in exercises, and tasks to do in other contexts.

EDUciencias is a graphic multimodal smartbook. This was detected while analysing the elements of the book, but also with the strong application of the multimedia principle on every level. Yet, there is no use of motion modalities by unknown reasons.

During the analysis of the applied strategies to enhance learning proposed by psychology, cognitive and learning sciences, it was discovered that design could help to achieve them at various levels. The scrutiny was organised looking into each e-learning objective.

Accordingly, design can help to guide children to find relevant information, minimising extraneous processing. On a meta level, this can be achieved through the selection and presentation of relevant content only. On a micro and macro level, the contribution is made through screen design following various techniques, such as typographic variations and use of styles, visual hierarchy, the application of Gestalt rules and simplification techniques.

Assistance to understand the material and memorization could also be boosted by design. This goal is about taking into account the cognitive limitations and design for it. To manage learner's essential processing in EDUciencias, the techniques are mostly applied on a meta level. By making use of humans double channel capacity, including words and graphic simultaneously. Moreover, the smartbook uses strategies to organise the content such as segmenting, sequencing, and memorable summaries. In a micro and macro level, the designs try to improve the quality of the material by using manageable chunks of information, using different kinds of graphics and using representational elements.

Engaging and motivating the students with learning is crucial, and design can help too. To foster generative processing at a strategic level, it is necessary to give control and know the learner. Designers do it through user research methods. At lower levels, design makes a great contribution with assuring an aesthetic and pleasant e-learning environment and giving clear and recognisable controls.

Finally, there were detected other design techniques that are not proposed by the learning sciences, but that designers use and which can be beneficial to reach the e-learning objectives. By providing a well-formatted text to assure comfortable reading, designers can avoid the use of extra cognitive resources in decoding the text. Hence, the processing capacity is free to understanding the content of the text. Correspondingly, the consistency in formatting each element and the screens

avoids distracting the student; being predictable gives satisfaction to the learner. Instead of exposing the student to understand a new language each time, it leaves its capacity free for learning the scientific concepts.

Chapter 5 Conclusions

This is the last chapter of the dissertation; it will conclude and end the research that was motivated by these two research questions:

- How science concepts are presented in an e-learning environment like EDUCiencias?
- What considerations should designers take into account to enhance learning?

A summary of findings and conclusion would be presented. To organise them, they will be presented in relation to each of the research objectives:

1. *Gather* all relevant matters to understand and *identify* strategies to enhance the learning of science concepts for primary school children in e-learning.
2. *Construct* a framework for analysing an e-learning environment.
3. *Analyse* and *outline* some of the design considerations for enhancing learning in EDUCiencias.

To conclude, recommendations will be proposed. They will be based on the findings proposing further investigation on this topic.

5.1 Summary of findings and conclusions

In relation to the first research objective, there are two main conclusions. The first one is the similarity between information design and e-learning instruction. The second one is the identification of the strategies to facilitate learning proposed by the learning sciences that can be supported by design techniques.

A major finding is the clear role of design to support e-learning due to its multimodality nature. The findings of this study suggest that particularly, information designer share the same goals that multimedia e-learning. It was also found that design can support e-learning principles.

Table 5 summarises the findings of this research objective, by showing how design can support e-learning. The table is divided, for a better understanding, in the three learning objectives. Also, it introduces many design techniques supported by various authors to enhance those strategies.

About the second research objective, an analytical framework was constructed. The framework intends to be applied in particular cases to juxtapose what it is found in

the theory with real examples. The three-level scrutiny helps to see how the theoretical strategies could be applied at various degrees in smartbooks. Furthermore, the framework was useful and easy to apply. Conceivably, it could be replicated in other e-learning environments. Particularly, the matrix that identifies the design techniques applied in the product (Table 5) could be a tool for either analysis or planning of the design decisions to enhance learning.

The findings of the case study and research objective four (*Analyse* and *outline* some of the design considerations for enhancing learning in EDUCiencias) are the result of the discussion. The investigation has shown the close relation between the product's structure with the theoretical approach; in this case, it was appreciated at two levels. On one side, the software was divided into the official disciplines suggested by the education regulatory body; and, on the other hand, an educational sequence was reflected in a linear flow among its unit's screens.

The analysis has identified that the context of use affects the product's design; in this case, the e-book does not include any sounds owing to its context. As the product is intended to be in a class where each child has a computer, it is assumed that sounds could be distractive. For this reason, the smartbook appears to have abandoned the possibility of using one of the two channels for perceiving information. Nonetheless, as the product is utilised in a classroom, the teacher can use the available channel. A multimodal graphic dimension enriches the visual channel; using text, images, graphics, and spatial relationships to convey meaning.

The discussion unveiled that design can contribute to enhancing e-learning at different levels. Most of the strategies to support e-learning are intended and applied in EDUciencias on a meta level, except the strategies to minimise the extraneous processing that are mostly related to the sensorial perception of the material. Although, all of the strategies that do not include sound were applied, it was detected that some of the strategies could be implemented even further to support an even better learning experience.

5.2 Recommendations and future research

This study ends with two final recommendations.

1. The importance of incorporating the learning sciences know-how as an input for designers.
2. The suggestion for more investigation in this research.

It was found that design naturally uses other disciplines' knowledge to support design decisions. Particularly, in this study, the knowledge of cognitive and behavioural sciences, and psychology to enhance science e-learning at primary school level is suggested. Their research is a valuable input to design e-learning environments.

Table 11 summarises the strategies from learning sciences to enhance e-learning for primary science; it also includes design strategies to enhance learning arose

Table 11 Matrix of strategies and design techniques at different levels

Goal	Principle	Application on micro level	Application on macro level	Application on meta level
MINIMIZE EXTRANEOUS PROCESSING	**Coherence**	• Isotype method		• Relevance Principle • Isotype method
	Signalling	• Typography differentiation • Visual hierarchy • Pointed words • Pointed elements • Attention grabbers	• Typography styles • Type hierarchy • Space structured text • Visual hierarchy • Content structure	• Access structure
	Redundancy		• No spoken and written text simultaneously	
	Spatial Contiguity	• Use of Labels • Gestalt principles	• Use of Captions • Text/graphic relations • Gestalt principles	
	Temporal Contiguity		• Narration and graphics simultaneously	
	Simplification	• Thoughtful reduction • Simple representations and forms • Isotype principles • Background elimination	• Layers of information • Interactive layers • Clear backgrounds • Low granularity and density	• Use of pictograms • Selection of material according to learner's knowledge
	Consistency	• Use of styles • Labelling	• Use of grid or consistent layout	• Being predictable
	Comfortable reading	• Typography settings • Legibility	• Text/graphic relations • Text layout • Typography styles • Type hierarchy	• Readability • Use of relevant vocabulary and syntax
MANAGE ESSENTIAL PROCESSING	**Multimedia**	• Use of Labels • No abstract images	• Use of Captions • Different type of graphics	• Use of Visualisations • Isotype principles • Different type of graphics
	Modality	• Use audio rather than on-screen text		
	Pre-training			• Content structure • Product structure
	Segmenting	• Chunks and Blocks of information • Sequencing and segmenting	• Interactive layers	• Chunks and Blocks of information • Sequencing and segmenting
	Limited short memory	• Chunks and Blocks of information		• Chunks and Blocks of information • Repetition • Content structure (summaries, key facts)
FOSTER GENERATIVE PROCESSING	**Personalization**	• Conversational text style • Balloon dialogue representations		• Appropriate text style • Use of dialogues • User centred design
	Voice	• Use human voice for audio narrations		
	Embodiment	• Use human characteristics for characters		• Characters similar to learners • User centred design
	Image			• Children like on-screen characters
	Storytelling	• Narrative representations • Narrations		• Use a story or familiar situation as a thread • Content structure • Product structure
	Learner control	• Clear Controls		• Give self-pacing control
	Prior-Knowledge activation	• Questions, familiar situations		• Start introduction retrieving their prior knowledge
	Dynamic visualisation		• State the function (title, caption)	
	Aesthetic-usability	• Harmony • Proportion • Appealing graphics • Pleasant type setting	• Harmony • Proportion • Composition • Use of grid	• User centred design • Testing

in the discussion. Furthermore, the matrix shows how to support these strategies with design techniques that are widely used and backed by many designers. Finally, based on the reflection and extrapolation of how the strategies were employed in EDUciencias, the matrix classifies on what level can be the design techniques applied.

This matrix can be utilised either as a tool for design or as a tool for analysis. For teams designing e-learning instructional experiences, the matrix, as well as the literature review, serves as a summary of the relevant matters to design for this kind of products. To plan the principles and structure of the environment, designers can use the design techniques and strategies on a meta level. For the actual design and display of information on-screen, the techniques on a micro and macro level will help to achieve the e-learning objectives.

The table can also serve as an analysis tool too. It is not intended as a checklist because not all the strategies need to be applied. However, it can be used to improve current environments by checking which strategies are used, which were consciously avoided and to reflect on which ones can be introduced or applied further.

The second recommendation is related to further studies. The case study was analysed based on observation about which strategies were used to strengthen learning and until which state; however, this scrutiny does not infer regarding the usefulness of the strategies. No study was done to evaluate if the strategies chosen were successful; further testing is necessary regarding this matter. For instance, Norman and Spohrer (1996) suggest that three dimensions of instruction need to be evaluated to develop a successful learner-centred e-learning environment: engagement, effectiveness and viability. Another example for evaluation, particularly for educational smart or e-books, as she called them, is developed by Paloma Díaz (2003). This framework is based on the educational usefulness and the usability, as it can be appreciated in Figure 11. Finally, user testing with children could be beneficial to compare the theory and the impact on the users.

In summary, this research contributes to envision the role of the designer in developing e-learning materia. It identifies important elements that designers can incorporate from the learning science community and can serve as a base for more in depth studies.

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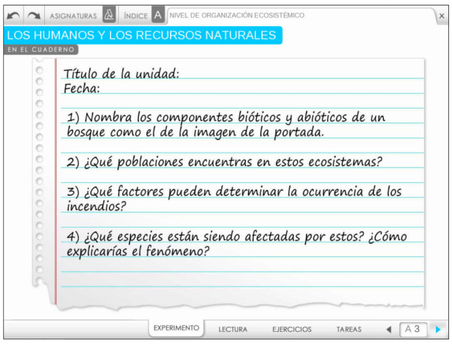
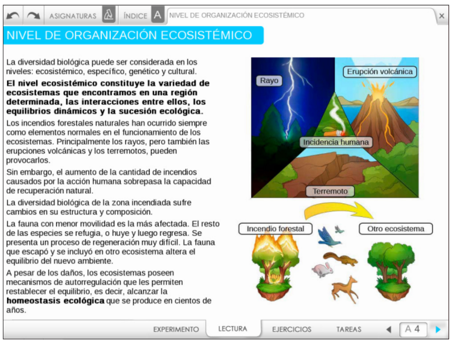
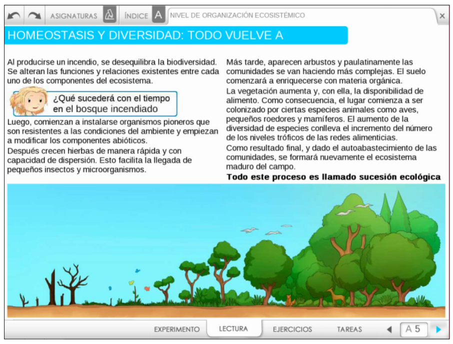
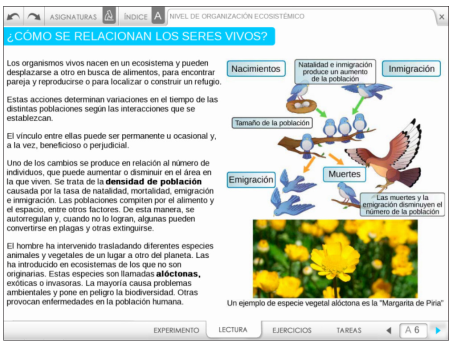
Appendix

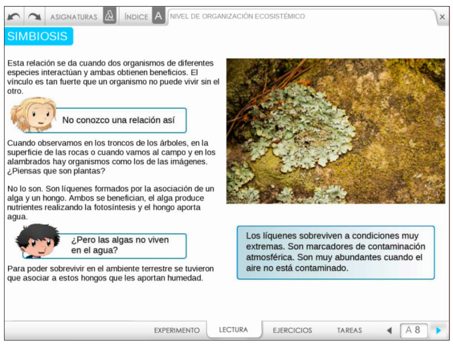
Appendix A: Screenshots



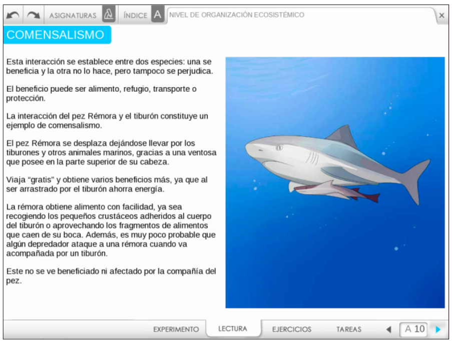


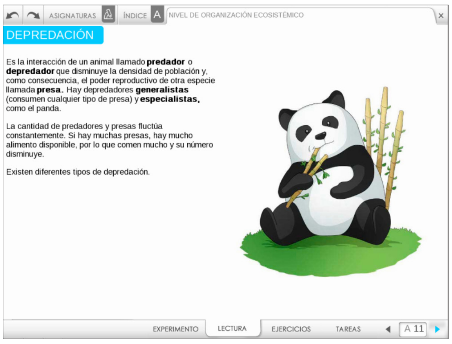


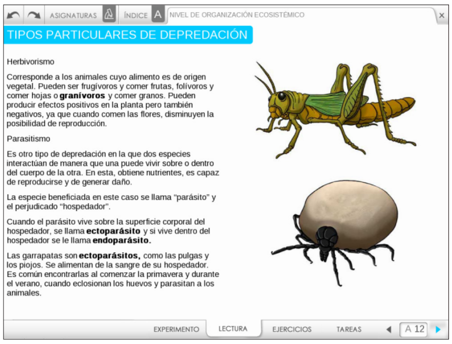




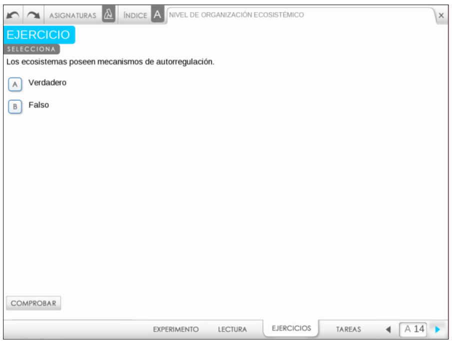

MUTUALISMO
¿Alguna vez has observado una imagen como la de la derecha?
Aves posadas sobre el ganado son muy fáciles de ver en nuestros campos. Se encuentran interactuando.
¿Por qué lo hacen?
Lo hacen porque ambos se benefician. El ave, ya que se alimenta de los pequeños insectos o arácnidos que están en la piel del ganado. Este, ya que se eliminan los organismos que le causan daño.
Este tipo de relación se llama mutualismo y los individuos pueden vivir uno sin el otro.
Esta interacción no solo se da con el ganado, también se puede dar con otros mamíferos como los carpinchos.
¡Nemo y la anémona de mar interactúan beneficiándose!
¡Claro! Nemo, el pez payaso, puede tolerar el veneno de la anémona. Además de permitirle vivir en sus tentáculos, lo protege de diversos depredadores de mayor tamaño que no toleran su veneno. A su vez, el pez payaso protege a la anémona de los peces que se alimentan de ella y de otros depredadores pequeños, de los que no puede defenderse.
EXPERIMENTO
LECTURA
EJERCICIOS
TAREAS
A 9

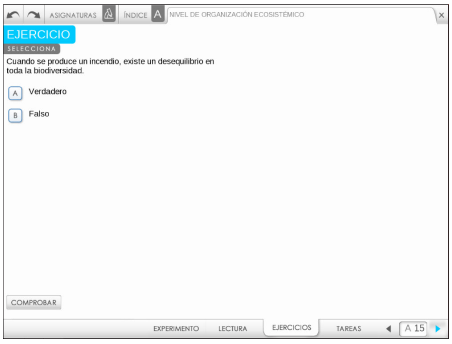

COMENSALISMO
Esta interacción se establece entre dos especies: una se beneficia y la otra no lo hace, pero tampoco se perjudica.
El beneficio puede ser alimento, refugio, transporte o protección.
La interacción del pez Rémora y el tiburón constituye un ejemplo de comensalismo.
El pez Rémora se desplaza dejándose llevar por los tiburones y otros animales marinos, gracias a una ventosa que posee en la parte superior de su cabeza.
Viaja "gratis" y obtiene varios beneficios más, ya que al ser arrastrado por el tiburón ahorra energía.
La rémora obtiene alimento con facilidad, ya sea recogiendo los pequeños crustáceos adheridos al cuerpo del tiburón o aprovechando los fragmentos de alimentos que caen de su boca. Además, es muy poco probable que algún depredador ataque a una rémora cuando va acompañada por un tiburón.
Este no se ve beneficiado ni afectado por la compañía del pez.
EXPERIMENTO
LECTURA
EJERCICIOS
TAREAS
A 10

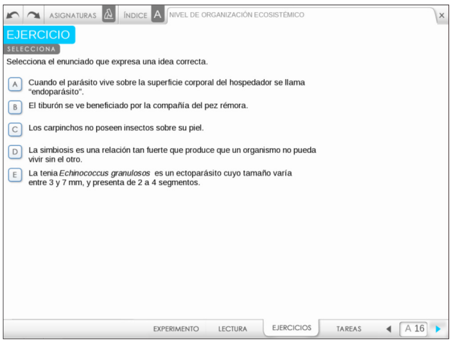

DEPREDACIÓN
Es la interacción de un animal llamado predador o depredador que disminuye la densidad de población y, como consecuencia, el poder reproductivo de otra especie llamada presa. Hay depredadores generalistas (consumen cualquier tipo de presa) y especialistas, como el panda.
La cantidad de predadores y presas fluctúa constantemente. Si hay muchas presas, hay mucho alimento disponible, por lo que comen mucho y su número disminuye.
Existen diferentes tipos de depredación.
EXPERIMENTO
LECTURA
EJERCICIOS
TAREAS
A 11

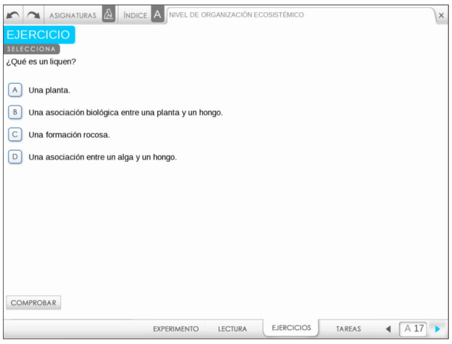

TIPOS PARTICULARES DE DEPREDACIÓN
Herbivorismo
Corresponde a los animales cuyo alimento es de origen vegetal. Pueden ser frugívoros y comer frutas, folívoros y comer hojas o granívoros y comer granos. Pueden producir efectos positivos en la planta pero también negativos, ya que cuando comen las flores, disminuyen la posibilidad de reproducción.
Parasitismo
Es otro tipo de depredación en la que dos especies interactúan de manera que una puede vivir sobre o dentro del cuerpo de la otra. En esta, obtiene nutrientes, es capaz de reproducirse y de generar daño.
La especie beneficiada en este caso se llama "parásito" y el perjudicado "hospedador".
Cuando el parásito vive sobre la superficie corporal del hospedador, se llama ectoparásito y si vive dentro del hospedador se le llama endoparásito.
Las garrapatas son ectoparásitos, como las pulgas y los piojos. Se alimentan de la sangre de su hospedador. Es común encontrarlas al comenzar la primavera y durante el verano, cuando eclosionan los huevos y parasitan a los animales.
EXPERIMENTO
LECTURA
EJERCICIOS
TAREAS
A 12

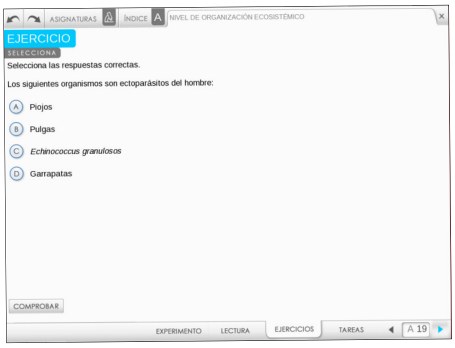

UN PARÁSITO MUY PERSISTENTE: ECHINOCOCCUS GRANULOSOS
En el Uruguay existen varias especies de endoparásitos que afectan la salud del ser humano, la de los perros o el ganado.
Consecuentemente, alteran la economía de un país, dado que provocan daños en la industria agropecuaria.
El ganado afectado por estos parásitos disminuye la producción de lana, cuero, carne y leche.
La tenia Echinococcus granulosos es un animal platelminto endoparásito cuyo tamaño varía entre 3 y 7 mm, y presenta de 2 a 4 segmentos.
Los parásitos adultos se fijan en el intestino del perro, por medio de ganchos y ventosas. El animal elimina huevos del parásito en su materia fecal que son ingeridos por un ovino, bovino, cerdo, equino o por el hombre. Así comienza a desarrollarse en ellos hasta formar el quiste hidático. Este produce la enfermedad llamada Hidatidosis.
El ciclo se cierra cuando el perro ingiere vísceras de un huésped intermediario con quiste hidático, y comienza nuevamente el desarrollo del parásito adulto en su intestino.
E. granulosus vista al microscopio óptico
EXPERIMENTO
LECTURA
EJERCICIOS
TAREAS
A 13

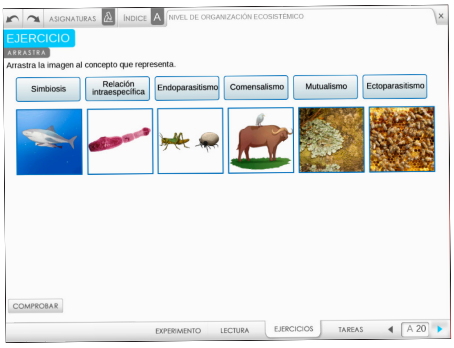

EJERCICIO
SELECCIONA
Los ecosistemas poseen mecanismos de autorregulación.
A Verdadero
B Falso
COMPROBAR
EXPERIMENTO
LECTURA
EJERCICIOS
TAREAS
A 14

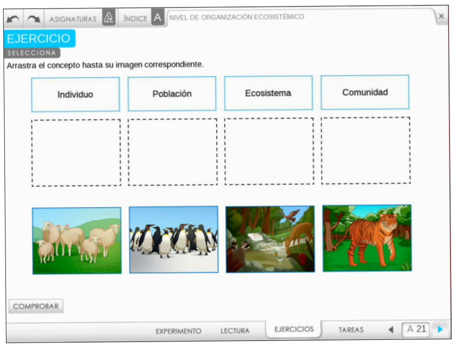

EJERCICIO
SELECCIONA
Cuando se produce un incendio, existe un desequilibrio en toda la biodiversidad.
A Verdadero
B Falso
COMPROBAR
EXPERIMENTO
LECTURA
EJERCICIOS
TAREAS
A 15

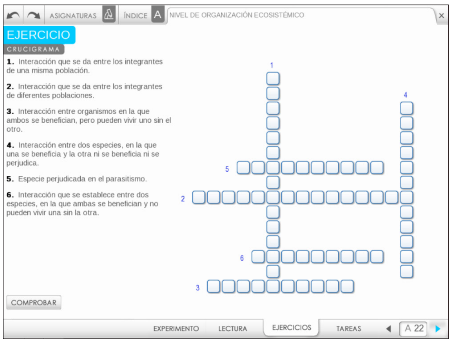

EJERCICIO
SELECCIONA
Selecciona el enunciado que expresa una idea correcta.
A Cuando el parásito vive sobre la superficie corporal del hospedador se llama "endoparásito".
B El tiburón se ve beneficiado por la compañía del pez rémora.
C Los carpinchos no poseen insectos sobre su piel.
D La simbiosis es una relación tan fuerte que produce que un organismo no pueda vivir sin el otro.
E La tenia Echinococcus granulosos es un ectoparásito cuyo tamaño varía entre 3 y 7 mm, y presenta de 2 a 4 segmentos.
EXPERIMENTO
LECTURA
EJERCICIOS
TAREAS
A 16

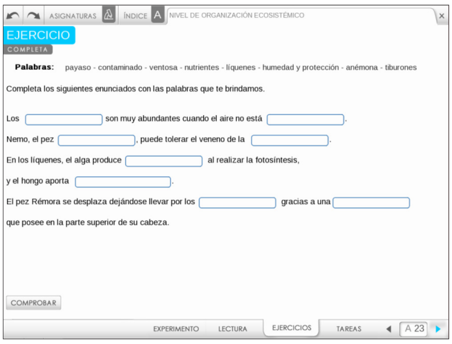

EJERCICIO
SELECCIONA
¿Qué es un liquen?
A Una planta.
B Una asociación biológica entre una planta y un hongo.
C Una formación rocosa.
D Una asociación entre un alga y un hongo.
COMPROBAR
EXPERIMENTO
LECTURA
EJERCICIOS
TAREAS
A 17


EJERCICIO
SELECCIONA
Selecciona las respuestas correctas.
Los siguientes organismos son ectoparásitos del hombre:
A Piojos
B Pulgas
C Echinococcus granulosos
D Garrapatas
COMPROBAR
EXPERIMENTO
LECTURA
EJERCICIOS
TAREAS
A 19


EJERCICIO
ARRASTRA
Arrastra la imagen al concepto que representa.
Simbiosis
Relación intraespecífica
Endoparasitismo
Comensalismo
Mutualismo
Ectoparasitismo
COMPROBAR
EXPERIMENTO
LECTURA
EJERCICIOS
TAREAS
A 20


EJERCICIO
SELECCIONA
Arrastra el concepto hasta su imagen correspondiente.
Individuo
Población
Ecosistema
Comunidad
COMPROBAR
EXPERIMENTO
LECTURA
EJERCICIOS
TAREAS
A 21


EJERCICIO
CRUCIGRAMA
1. Interacción que se da entre los integrantes de una misma población.
2. Interacción que se da entre los integrantes de diferentes poblaciones.
3. Interacción entre organismos en la que ambos se benefician, pero pueden vivir uno sin el otro.
4. Interacción entre dos especies, en la que una se beneficia y la otra ni se beneficia ni se perjudica.
5. Especie perjudicada en el parasitismo.
6. Interacción que se establece entre dos especies, en la que ambas se benefician y no pueden vivir una sin la otra.
COMPROBAR
EXPERIMENTO
LECTURA
EJERCICIOS
TAREAS
A 22


EJERCICIO
COMPLETA
Palabras: payaso - contaminado - ventosa - nutrientes - líquenes - humedad y protección - anémona - tiburones
Completa los siguientes enunciados con las palabras que te brindamos.
Los ____ son muy abundantes cuando el aire no está ____.
Nemo, el pez ____, puede tolerar el veneno de la ____.
En los líquenes, el alga produce ____ al realizar la fotosíntesis,
y el hongo aporta ____.
El pez Rémora se desplaza dejándose llevar por los ____ gracias a una ____
que posee en la parte superior de su cabeza.
COMPROBAR
EXPERIMENTO
LECTURA
EJERCICIOS
TAREAS
A 23


LAS ESTRELLAS DE MAR...
Relaciona e interpreta lo que sucede en la imagen de la portada de la unidad con el relato de las estrellas de mar.
Había una vez un escritor que vivía a orillas del mar, en una enorme playa. Allí tenía una casita donde pasaba temporadas escribiendo y buscando inspiración para su libro.
Una mañana, mientras paseaba a orillas del océano, vio a lo lejos una figura que se movía de manera extraña, como si estuviera bailando. Al acercarse, vio que era un muchacho que se dedicaba a juntar estrellas de mar de la orilla y lanzarlas otra vez al mar.
El hombre le preguntó al joven qué estaba haciendo. Este le contestó:
- Recojo las estrellas de mar que han quedado varadas y las devuelvo; la marea ha bajado demasiado y muchas morirán.
Dijo entonces el escritor:
- Pero esto que haces no tiene sentido. Es su destino, morirán y serán alimento para otros animales, y además hay miles de estrellas en esta playa, nunca tendrás tiempo de salvarlas a todas.
El joven miró fijamente al escritor, juntó una estrella de mar de la arena, la lanzó con fuerza por encima de las olas y exclamó:
- Para esta… sí tiene sentido.
El escritor se marchó un tanto desconcertado, no podía explicarse una conducta así. Esa tarde no tuvo inspiración para escribir y en la noche no durmió bien, soñaba con el joven y las estrellas de mar por encima de las olas.
A la mañana siguiente corrió a la playa, buscó al joven y le ayudó a salvar estrellas…
EXPERIMENTO
LECTURA
EJERCICIOS
TAREAS
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