Design and evaluation of Web-based Learning Environments using Information Foraging models

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Abstract
In this chapter methods and tools for effective design and evaluation of web-based learning environments are presented. The main aspect addressed by this proposal is that of increasing findability of information in large web sites of learning information content by applying methods and tools based on the information foraging model. It is argued that through this approach, issues of learning content structure and usability may be also addressed. In particular, we propose four different ways to have information foraging theory informing the design. Directives, to ensure proper learning content structuring and cues with strong scent, tools based on LSA to automate the design and evaluation process, methods to construct archetypal learner’s profiles from user data and added functions to realise collaborative information filtering and personal information patch creation, thus allowing learners to organize their reference materials in a meaningful and constructive way.

KEYWORDS
Web-Based Learning Environments, Asynchronous Education, Information Foraging, Information Scent, Interaction Design, usability, findability
INTRODUCTION
During the last years, there has been a growing demand for adopting innovative approaches to the design and delivery of web based education. The benefits of interactive hypermedia and the increasing popularity of the web open a new paradigm for the authoring, design and delivery of learning material, and has carved the path for the so called Web based Learning Environments (WBLE). It has been widely accepted that the hyper-medial structure of the web could promote learning. Some researchers characterize the web as an active learning environment that supports creativity (Becker & Dwyer, 1994). According to Thuring, Mannemann and Haake (1995), the web encourages exploration of knowledge and browsing behaviors that are strongly related to learning.

Theories of learning standing on theoretical bases of objectivism and constructivism (Jonassen, 1992; Vrasidas, 2000), can inspire the design and usage of WBLEs. The aspects that each theoretical standpoint puts more emphasis in, can transcribe the design and development of certain WBLEs and the associated learning activities that are followed. One of the most promising constructivism-based models, which emphasizes the role of social interactions and cultural artifacts in triggering cognitive elaboration and resulting in co-construction of knowledge among the members of communities of practice (Lave & Wenger, 1991), for designing WBLEs is the one proposed by Duffy and Kirkley (2004). The basic pedagogical goals of the model are to engage students in inquiry, provide structure, support collaborative inquiry, conduct performance-based assessment and promote reflection and transfer.

Apart from the pedagogical design aspects that have to be followed, the interaction design of the WBLE plays a significant role in how these principals come into real practice. According to Duffy and Kirkley (2004), effective design of such systems should encompass 2 basic entities. The learning content management system (LCMS), and a separate, although tightly interconnected by means of hyperlinks, learning management system (LMS). Even if in the second module exists an important body of design knowledge as well as good practices and plethora of useful tools (Forum, calendars, assignments, etc) this is rarely the case for the first one.

For example, concerning the links of learning content that lists the learning resources on a single screen lead to a linear reading strategy by the students. In a WBLE realized according to the aforementioned model, when the designers developed a new interface where the resources were linked to the task, the students found it more beneficial, and there were few students that reported that they read everything first (Gunawardena, 2004). In addition, from a psychological perspective, the learner needs to consult links with high-quality residues, in order to proceed seamlessly, establish a flow state and not get overly frustrated while she is involved in the task (Csikszentmihalyi, 1990). Therefore, apart from the disposition of links of learning content, the proximal cues of such links (i.e the hyperlinks’ descriptions), that give the learner a sense of the access path of the desired information sources, are crucial for the success of the learning task.

As a result, the process of design and adaptation of appropriate learning content with respect to the needs and particularities of the medium, could serve efficiently even pedagogically neutral WBLEs, since the effective separation of learning content from learning tools greatly enhances its organization, reusability and maintainability. This
is a critical point, since one of the most common pitfalls in WBLEs is the use of existing course materials without adapting them to the online delivery method. Thus, often learners, are unable to find, evaluate, and use materials relevant to their studies, which renders learning activity problematic. Although the key requirement still remains the quality of the instructional design itself, this should not be treated as an excuse to overcome the aforementioned issues. Educators and developers should be concerned about determining their role and developing adequate techniques to diminish any negative influence of the tools’ design on the educational process (Tselios, Avouris, Dimitracopoulou & Daskalaki, 2001). Towards this goal, we argue that concerns such as learning content design, findability, proper information structure, and overall usability issues should be properly encapsulated into the WBLE’s course design lifecycle.

Findability is defined as the degree to which a particular object is easy to discover or locate and consequently the degree to which a system or environment supports navigation and retrieval (Morville, 2005). The concept of findability is of fundamental importance for the web in general, and WBLEs in particular. The problem is that findability is a concept that lies between user-centered design, engineering, and proper learning content creation. This mutual responsibility is usually threatened by the chance that no stakeholder considers herself as accountable. Furthermore, the usability of an educational environment is related to its pedagogical value (Kirkpatrick, 1994) and evaluation of its usability should be part of the processes of establishing its quality. According to Hayes (2000), user centered design of online course delivery systems should examine in particular the effort required by the user to take ownership of the system’s functionality and should concentrate on ease of use. While there is a large corpus of theoretical and practical knowledge relating to software usability evaluation in general and educational software in particular, there are not well-established techniques relating to WBLEs usability evaluation (Heines, 2000).

The main underlying idea of our proposal is that the theoretical notion of information foraging could serve as a unifying glue to properly address the aforementioned issues. In our approach, we examine the notion of architecture for e-learning systems, from an information architecture perspective (i.e. structure of learning material). Information architecture is the practice of structuring information (knowledge or data) for a purpose. We do not investigate the issues of infrastructure or component implementation, from a technical point of view, neither we attempt to explain how e-learning systems are implemented and operated. In particular, we argue that efficient and effective learning content presentation and structuring is of central importance, for delivering a deep and constructive learning experience via WBLEs. Boland (1987) claims that the information is inward-forming, thus a mediator between knowledge and the learning ‘process’. Therefore, it is crucial to understand the way learners’ interact and retrieve information within these systems using theoretical models of learners’ behavior. This is not to argue that information design and architecture can cause learning. We perceive the issue of proper WBLE design as a means of enabling possibilities to learn. Learners themselves will seek and acquire needed elements of information. Independently of the pedagogical model adopted, this process requires knowledge acquisition, integration of usually heterogeneous knowledge “segments”, evaluation of the information, goal reformulation and actions selection, leading to deeper understanding and knowledge construction. Designers should seek to improve
the abilities of learners to manage and navigate knowledge resources and create environments that increase the capacity of learners to function and forage for their own knowledge. It is of paramount importance that the mediation of the WBLEs is transparent and intuitive and does not interfere with the learning ‘process’.

In this chapter we will present a set of tools for design and evaluation of WBLEs. For this reason, the basic aspects of information foraging theory are presented first. The presented accumulated knowledge will be unified and explained under the prism of the notion of information foraging theory and will be embedded into a set of conceptual design and evaluation tools aiming to lead the realisation of WBLEs. Finally, tools to automate parts of the design and evaluation process will be presented as well as future directives to extend the proposed approach.

BACKGROUND
Models of Information Foraging
The core idea of *Information Foraging* theory (Pirolli & Card, 1995) is that information seeking and retrieval is analogous to the food foraging mechanisms developed by anthropologists and ecologists (Stephens & Krebs, 1986). The user adapts her behaviour (or even the structure of the system interface) in order to maximize her information gain per specific effort (unit cost). The theory refers to cognitive activities associated with assessing, seeking, and handling information sources.

In exploring and searching for information in the web, users become recipients of many and multiple “segments” of information. While navigating through different information clusters, users assess the appropriateness of following a particular path by considering a representation, usually a textual or graphic description, of the distant content. Furnas (1997), coined the term “residue” to describe the hint that a representational object holds (e.g. a hyperlink) of what lays behind it. Residue was recast and refined by Pirolli (1997) as information “scent” and defined as a user’s “(imperfect) perception of the value, cost, or access path of information sources obtained from proximal cues, such as WWW links”. Thus, in the context of WBLEs, information scent refers to the learner’s use of *proximal cues* – snippets that exist in the environment she interacts with, such as text and graphic hyperlinks - in judging information sources and navigating through information spaces that will allow her to retrieve valuable information and acquire knowledge. If the scent of information is sufficiently pungent, learners will be generally more able to find, evaluate, and use materials relevant to their studies.

*CoLiDeS* (Comprehension-based Linked model of Deliberate Search) is a similar comprehension-based cognitive model explaining users’ information foraging in the WWW (Kitajima & Polson, 1997). According to CoLiDeS, the cognitive processes that mainly determine users’ information foraging behaviour are parsing, focusing, comprehension and selection and every low-level action of the user is a two phase process (Blackmon, Polson, Kitajima & Lewis, 2002). During the *attention phase* the user creates a mental representation of the page by dividing it into a collection of sub-areas. Subsequently, the user is focusing on a sub-area that she believes is semantically closer to her goal. Following, during the *action-selection* phase, the user comprehends all the widgets in the sub-region she has focused and chooses to act on the one whose description is perceived to be closer to her goal.
We argue that study of these predictive models is of major importance in the frame of WBLEs. In an information-rich world, like a WBLE, the real design problem to be solved is not how to collect more information (e.g. learning content), but rather to increase the amount of relevant information encountered by a learner as a function of the amount of time that the learner invests in interacting with the system. The information architecture of the system determines the time costs (resource costs) and opportunity costs associated with exploring and finding information. Learners’ attention affordances are limited and they have to be spread optimally throughout a learning task so that maximum learning gains can be achieved. If a learner can deploy effective search strategies within the WBLE ecology, the opportunities for knowledge building and learning are greatly enhanced.

For example, a learner often has to combine information from various patches of the site to extract personal meaning and understanding. Important information foraging decisions include reflections on how much time to spend on processing a collection of information or whether or not to pursue a particular type of information content (information diet). While exploring an information patch, there will be a point where the information scent goes below some threshold. It’s the point where the learner realizes that the benefits (in terms of information gain) of staying at the specific information patch are significantly diminished. Thus, she decides to leave the specific area of the WBLE she was exploring in order to search for a more profitable hypertext area.

Understanding Courseware Offered in WBLEs
In an effort to model various approaches on learning, Mayes and Fowler (1999) developed a “framework for understanding courseware” that links a theory of learning to certain kinds of WBLEs and associated interaction and information design requirements for each category as illustrated in Figure 1. We argue that by combining the ascertainments of this model with the insight that the information foraging models gives, the problem of effective design and evaluation of WBLEs could be handled and tackled more efficiently.

![Figure 1. Mayes and Fowler’s (1999) taxonomy of courseware](image)
Mayes and Fowler describe the basic “unit of conceptual learning” as a cycle. The main stages of the learning cycle refer to conceptualisation, construction and dialogue. **Conceptualisation** refers to the learners’ initial contact with other peoples’ concepts. This involves an interaction between the learner’s pre-existing framework of understanding and a new exposition. It is conceived as the basic mechanism of learning according to objectivist approaches. **Construction** refers to the process of building and combining concepts through their use in the performance of meaningful tasks like problem-solving, laboratory work, writing etc. This stage constitutes the core of the learning opportunities according to constructivists. In education, however, as Laurillard (1993) has pointed out, the goal is testing of understanding, often of abstract concepts. This stage is best characterised in education as **dialogue**. The conceptualisations are tested and further developed during conversation with both tutors and fellow learners, and in the reflection on these (Mayes & Fowler, 1999).

Mayes and Fowler discriminate between three kinds of courseware appropriate to each stage of the learning cycle judging from a learner-centred perspective. **Primary courseware** is courseware that just conveys subject matter and is appropriate for conceptualisation. The quality of primary courseware will be mainly determined by the match between material and learner on the dimensions of conceptual demands and requirements for prior understanding. The main requirement for such systems is to match the characteristics of a system to the expectations and knowledge of the user. Interaction between the learner’s prior understanding and the primary exposition produces just an initial interpretation. What is crucial for this primary exposition is to orient the learner towards the subject matter. Primary courseware should also provide the learner with the appropriate structures on how to navigate and find appropriate information. Learners using WBLEs seek information while looking for answers to their questions and achieving their goals.

Prior to this, the designer should organize learning content with respect to the learning goals, the pedagogical model adopted, and the particularities of the web as a medium. Information should be well structured and organized at the website level, page level and paragraph or list level to reduce the chances of learners becoming bored, disinterested or frustrated. As a result, models to explain learner’s behaviour while searching for information such as **information foraging theory** could directly inform design in those aspects by providing abstract cognitive models of the learner’s information search behaviour.

**Secondary courseware** describes the environment and set of tools by which the learner performs learning tasks, and the tasks (and task materials) themselves (Mayes & Fowler, 1999). Careful task analysis and model based evaluation, found to produce solid results and guide effectively design and evaluation of such systems (Tselios, Kordaki & Avouris, 2002). Proper information architecture, as derives from information foraging theories and established user research, is also crucial on the success of a learning scenario. Available exploratory tools should be efficiently interconnected with learning content. Possible approaches are tunnel (assumes optimal content ordering), hierarchical (top down decomposition) and matrix (relaxed hierarchy) structuring of web pages (Danaher, McKay & Seeley, 2005). Hybrid designs are a mix of the aforementioned approaches, each of which can be described along the continuum from matrix and tunnel designs. The latter form allows the user to engage in discovery learning while still maintaining the focused forward movement
of the tunnel program (Danaher, McKay & Seeley, 2005). However, the most crucial aspect is the basic suitability of the task imposed by the tutors for its educational purpose. To evaluate the wider usability of this kind of courseware will involve devising cognitive measures of conceptual engagement (Garrison, Anderson & Archer, 2001).

Tertiary Courseware is material which has been produced by previous learners, in the course of discussing or assessing their learning tasks. It may consist of dialogues between learners and tutors, or peer discussions, or outputs from assessment. Tertiary material can refer to the questions, answers and discussion that are typically posted to an asynchronous conferencing system. Other more sophisticated applications such as tools to provide collaborative filtering discussed in the next section, can be also used for mediating communication or collaboration between students and teachers.

In the following section we present our approach for design and evaluation of WBLEs, using the deeper understanding provided by Mayes and Fowler’s (1999) taxonomy as well as the models of information foraging. Specifically we argue that predictive models of human behavior can be used as a way to understand and interpret the behavior and searching strategies of learners during information foraging in a WBLE.

DESIGN & EVALUATE WBLEs BASED ON INFORMATION FORAGING

Information foraging can provide much-needed coherence and insight and lead both the design and evaluation process of WBLEs. However, it should be stressed that, we do not underestimate the value of established research based results and guidelines (Nielsen, 2000; Koyanl, Balley, & Nall, 2004). For example, we should highlight that studies report that content is more important than navigation, visual design, functionality, and interactivity (Nielsen, 2000). This is even more true in the case of WBLEs. On the contrary, we argue that results from user studies should be equally taken into account together with the notion of information foraging.

As a result, we propose an extension of the traditional design and evaluation models of WBLEs. We distinguish the mediating and aligning role of information foraging theories, as a tool to properly embed pedagogical models, take into account information architecture issues and encapsulate usability research towards formulation of our design and evaluation approach. By building on this notion, we propose four new tools that could inform the design and evaluation process.

a) First, specific directives that comply with information foraging theory, and provide design with strong information scent and rich information patches. In addition they are coupled with summarized, established, research-based knowledge related to web design and information architecture.

b) Our list of directives is supported with a tool capable of automatically evaluating the semantic appropriateness of the hyperlinks’ descriptions presented in a WBLE. In addition, we envisage a tool to automate the card sorting procedure which is described in the future trends section.

c) In addition, ways to provide valuable insight while in the process of interpreting user interaction data such as log files are possible through the notion of information foraging.
Finally, the ideas proposed do not tackle only issues mainly related to the LCMS module of the WBLE. For instance, allowing learners to take advantage of the trails followed by others through collaborative information filtering (Wexelblat & Maes, 1999) gives them the opportunity to reflect upon other colleagues’ learning strategies, thus giving richer collaboration and dialogue possibilities.

Therefore, by having the aforementioned models directly informing the design and evaluation process of WBLEs, we argue that two distinct types of impasses could be tackled. One type of problems can be detected at a Web page level due to inadequate scent emitted from the proximal cues in Web pages. Another type of impasse can be traced at a Web site level, and is caused by flaws in the information architecture of Web-based educational systems.

At a Web page level the categories of possible problems that could be identified and the solutions proposed are:

- **Weak Scent Cues.** When a correct link is not semantically similar to the learner’s goal and there are no other correct links that have moderate or strong similarity, the learner is faced with a cognitive dead-end. Usually, learners encounter inadequate scent on Web pages that use short and/or ambiguous link labels. The above ascertainment well confronts with research based results. Resnick and Sanchez (2004) conducted a controlled experiment to explore the relative value of a user-defined structure versus user-generated labels. Resnick and Sanchez’s data shows that labels matter more than structure. Therefore, good labels and links are of utmost importance for a WBLE design. Feedback on learners’ location should be provided, combined with descriptive tabs and menus. Despite careful labelling, cues as well as content delivery should be presented having in mind the observed behaviour of learners while interacting with a web page. Studies (Morkes & Nielsen, 1998; Nielsen, 2000) report that about 80% of users scan any new page and only 16% read word by word. Those findings well confront with the information foraging models presented in the previous section.

- **Competing Cues.** A competing cues problem occurs when a page contains one or more links that are semantically similar to the learner’s goal but do not lead to the targeted information resulting to cognitive overload, frustration and in a loss of orientation. The cause of this problem can be either the choice of semantically improper proximal cues or the existence of highly general link labels. A solution to such cases is greater specificity and clarity that makes individual links distinct from each other. A single word may not emit sufficient scent but on the other hand too many words can be difficult to read. Text links usually provide much better information about the target than graphics do (Nielsen, 2000). Also, items that are in the top center of the page or left and right panels have a high probability of being considered links. Research indicates that users tend to stop scanning a list as soon as they see something relevant with their goal. Thus important items should be placed at the beginning of lists. (Spyridakis, 2000). The aforementioned argument has been backed by research studies as well. If headings are too similar to one another, users may have to hesitate and re-read to decipher the difference (Morkes & Nielsen, 1998), a result which is fully
compatible with the information foraging theory. Headings should provide strong cues that orient users and inform them about page organization and structure.

- **Unfamiliar Cues.** This occurs when the WBLE users do not comprehend a link due to varying reading experiences, topic knowledge and culture backgrounds – a common phenomenon in web environments. Possible reasons are technical terms or unusual words that are novel for a particular learners’ segment and only learners who comprehend the meaning can actually perceive the scent and then click on it. To avoid confusing the user, the title for a page should be consistent with its heading in the content area. Familiar words should be used since words that are more frequently seen and heard are better and more quickly recognized (Leech, Rayson & Wilson, 2001). To ensure that links are effectively used, designers should use meaningful link labels, provide consistent clickability cues, and designate when links have been clicked (Miller & Remington, 2000).

Concerning the physical layout of a web page, users generally look at the top center of a page first, therefore all critical content and navigation options should be toward the top of the page. Well-written headings are an important tool for helping learners scan quickly. Additionally, users prefer moderate amounts of white space. Especially on content they like white space to separate paragraphs. In a related study use of whitespace between paragraphs and in the left and right margins increased comprehension by almost 20% (Lin, 2004).

In addition to this, to further optimize reading comprehension, the number of words in sentences and the number of sentences in paragraphs should be minimized so as the text can be more scannable (Nielsen, 2000). An optimal result seems to be obtained when a sentence does not contain more than 20 words and a paragraph does not contain more than 6 sentences. Further at the point, since in the frame of WBLEs reading speed is most important, research suggests using longer line lengths (75-100 characters per line - Dyson & Haselgrove, 2001). Additionally, reading tasks seem to benefit from scrolling. Scrolling allows readers to advance in the text without losing the context as may occur when they are required to follow links. Paging allows learners to construct better mental representations of the text as a whole and to remember the location of the information they found. Research (Schwarz, Beldie & Pastoor, 1983) shows that inexperienced users prefer paging.

The main goal of a WBLE is to provide an environment that promotes learning and knowledge building, thus learners will rarely have extended knowledge of the topic covered. Although there might be some learners that have well-formulated goals and abundant relevant knowledge, usually this is not the case. Therefore, volume and proper structure of information and learner-system interaction greatly determine the efficiency of the learner to forage and acquire meaningful information. According to Rosenfeld and Morville (1998), identifying the right structure depends on how much familiar the learners are with the taxonomy or classification of the content of the WBLE. **Exact schemes**, such as alphabetical order or organizational structure, are best used when it is certain that learners know the specific labels for the information they are seeking. **Ambiguous schemes**, such as organization by topic area, are preferred when the learners may not know keywords or specific content names, or when they
may need to browse through the content to find what they need. Other issues that can be tackled referred to the overall learning content architecture with the proposed design solutions are:

- **Too Abstract Starting Nodes.** The starting pages of the WBLE-learner interaction may be so general that none are more than weakly similar to a particular subject, thus reducing the probability that the learner will select the ‘correct’ path. This situation can be resolved by making less general the links during the first steps of the learner so that they can emit enough scent for his learning activity.

- **Misclassified Nodes.** The designers of the WBLE may have misclassified either a page containing a concept description, so that picking links that seem closer to the learner’s goal may not lead to the information he seeks. Different learners may try different ways to find information depending on their own interpretations of a problem and the layout of a page. Some learners find important links easily when they have a certain label, while others may recognize the link best with an alternative name. So, establishing alternative ways to access the exact same information can help some learners find what they need (Ivory, Sinha, & Hearst, 2001).

- **Too Long Information Paths.** Long information paths usually have the intrinsic problem of too abstract starting pages mentioned above. In a broad, shallow structure, a larger number of more specific headings appear on a web page, raising the probability of a close semantic match to a learner’s goal and thus a shorter information path. In a well-designed WBLE, scent should increase as the learner traverses an information path and gets closer to accomplishing her goal. A modest change in the probability of selecting the correct link at each step has a major impact on the overall success rate. Research has shown that the likelihood for a user getting frustrated and unsatisfied is significantly increased after 3 clicks (Huberman, Pirolli, Pitkow & Lukose, 1998), therefore lengthier paths should be avoided.

- **Insufficiently Specific End-points.** The end-points of an information path may not be sufficiently specific. In a situation like this the page a learner visits in the end of his information seeking path retrieves an unreasonably large number of information objects. This can lead the learner to a cognitive overload and cause frustration and disappointment. As the learner traverses her information path she should be offered gradually more and more specific information in the domain she is studying.

The proposed tools address mainly the kind of primary courseware of the Mayes and Fowler’s taxonomy, mainly learning content design issues in the LCMS module as described previously, but also touch aspects related to secondary and tertiary courseware. In particular, the proposed specific directives, automated tools and data log files analysis through the lens of information foraging can ensure a well-designed content structure that orients the learner and helps him navigate towards the most beneficial learning material. The goal is to provide a structure within which the learner is engaged in inquiry, critical thinking and problem solving relevant to the performance objectives and thus support their learning process. Indeed, the structure is meant to permit the learners to expend their energy focused on problem solving related to the core concepts rather than to the content structuring and findability issues.
Lack of adequate information structure cannot be tackled using a powerful search engine inside the WBLE. When clear labels and prominent navigation options are established, users tend to browse rather than search. Searching is no faster than browsing in this context. (Katz & Byrne, 2003). Even if search engines are used they are not a substitute for good content organization (Nielsen, 2000) and do not always improve learners’ search performance.

Design of a WBLE should be not simply viewed as a means for proper content delivery but also as key determinant of its trustworthiness and credibility. For motivated learners, ineffective design (busy layout, small print, too much text) has a significant negative impact on perceived credibility (more than the corresponding good effect of a good design - Sillence, Briggs, Fishwick & Harris, 2004). Even affective aspects of the user interface such as chromatic model combinations (Papachristos, Tselios, & Avouris, 2005), could influence significantly the learner’s motivation and engagement with educational environments.

Another approach of understanding user behavior in a web site is based on a posteriory monitoring of the behavior of many users by using machine learning and data mining techniques (Srivastava, Cooley, Deshpande & Tan, 2000) in an effort to associate the observed actions of the user with her goal. Such methods have been also used in the context of e-learning systems to understand learners’ behavior and extract valuable information for their design and evaluation (e.g. Pahl, 2006). Most of these methods are based on the analysis of server log files and thus they have some intrinsic problems of missing data, mainly due to the nature of the medium and the stateless nature of the http protocol. Another implication of the information foraging theory is that it can allow the analysis of learners’ paths from information in Web server logs.

Although there are many software tools for discovering usage patterns from Web server logs, none of them allows us to extrapolate user goals. Chi, Pirolli, Chen and Pitkow (2001) demonstrate a way – the algorithm IUNIS (Inferring User Need by Information Scent) - to take surfing patterns and infer the associated information need of a given user. IUNIS identifies the documents that a user accessed during a browsing session and the order they were accessed. Applying the Longest Repeating Subsequence (LRS) paths that are repeated by multiple learners can be identified, and therefore more likely to be relevant to a specific learning task or goal. Each of these repeated paths helps to trace back and cluster the learners together when similar needs are identified. Designers of WBLEs can then construct learner types, or “learner profiles”, for a particular system. By efficiently constructing learner profiles, developers can know their learners’ information diet and increase the profitability of items in their diets by decreasing the amount of resources expended when foraging for desirable items. By generating learner profiles from analyzing the server logs of an existing WBLE, future iterations of the environment can better meet its learners’ needs, leading to greater satisfaction and reducing the costs associated with foraging.

As discussed previously, another interesting idea that could substantially increase the learning effect of WBLEs is collaborative information filtering. Collaborative filtering allows learners to forage for information in groups much like a group of humans collaborate to hunt for food within an environment. By tagging a history of use to a digital learning object, a single learner can benefit from the foraging of others. Interaction history of other foragers is described by Wexelblat and Maes
(1999) as footprints which allow users to leave traces in the virtual environment. The interaction history of others, attached to an object can come from automated sources, such as access logs, or active sources, such as online papers that allow learners to leave commentary. Additionally, a learner could reorganize the virtual learning environment, having in hand functions such as wikis to organize personal representations of referenced material and information, thus creating (individually or collaboratively) novel and rich information patches. In this way, collaborative information filtering activities can increase the sense to which learners feel a part of a group. At the same time during such activities the learners are encouraged and motivated to persist in their inquiries by seeing other learners expending effort.

The proposed approach is compatible with the inspiring work of research reported by Guzdial, Rick and Kehoe (2001). They report the effectiveness of CoWeb - a collaborative website that facilitates open authoring where any student can edit or create pages. In real-life applications, this behavior is mainly attributed to the collaborative information gathering philosophy developed gradually by their tutors. For instance, they report cases of CoWeb being used as a collaborative bookmark, hotlist or glossary space where the entire class finds information, posts links into pages and extends the structure with new pages for new kinds of bookmarks. The result is a collaboratively produced information space that becomes a useful resource for anyone on the topic of the class and gets reused and expanded by future classes.

In another case students collaboratively produced a project library by posting their assignments after grading. Other students used the high-scoring projects as sources for ideas and, in programming classes, as sources for code that could be re-used in new projects. Occasionally, students from the first term revisited the CoWeb during the second term, answering questions and sometimes changing and improving their cases. As the project case library grew larger, some students began creating indices or recommendations of their favorite cases. In another class CoWeb was used to implement a form of “close reading” where students identified sections to discuss by placing asterisks around the phrases of interest, examined other students’ annotations and expanded on them on separate discussion spaces linked with each phrase. Thus learners were able to reflect upon their arguments and strategies and engage in a constructive dialogue that strengthens their own ‘sense making’ and thus, according to social constructivism, the learning outcome.

By expanding our view of the computer as a tool for solving specific problems to the computer as a medium that facilitates communication and shared knowledge construction, we can fundamentally change the way we think and learn (Perrone, Repenning, Spencer, & Ambach, 1996), thus presenting a novel form of tertiary courseware according to Mayes and Fowler’s (1995) vision. Collaborative authoring environments, such as wikis and highly interactive web technologies like flash and AJAX framework offer the opportunity to embed personal information patches, into next generation WBLEs, using visual notations such as concept maps to illustrate learning paths and correlate concepts with each other.

Automating Aspects of WBLEs Design and Evaluation Process
Research (Resnick & Sanchez, 2004) has shown that link labels matter more than content structure. Therefore, good link labels (i.e. emitting sufficient information scent) are necessary in a WBLE to properly guide learners to the information they
seek for their studies. In the literature, there is an abundance of rules and guidelines on providing efficient and effective link labels (Miller & Remington, 2000; Spyridakis, 2000; Nielsen, 2000; Koyanl, Bailey, & Nall, 2004). Among others these guidelines suggest that designers should support scanning of the page, use meaningful link labels that convey all the necessary information for their destinations, make sure that they are consistent with their targets, make sure that each link label clearly differentiates one link from another, provide consistent clickability cues, designate when links have been clicked, prefer using text for links rather than graphics and provide alt text and associated texts whenever graphical links are used.

Despite the abundance of guidelines concerning the appropriate ways to provide efficient and effective link labels, it is crucial—especially for practitioners—to offer an increased level of automation (Chi, Pirolli & Pitkow, 2000) in the design and evaluation process of WBLEs and provide an objective measure of the appropriateness of the hyperlink descriptions. One such tool that we have implemented to increase the usefulness and applicability of our proposal, is one that automatically evaluates the semantic appropriateness of the hyperlinks’ descriptions presented in a web-based environment (Katsanos, Tselios & Avouris, 2006). This tool, named InfoScent Evaluator (ISEtool), is capable of simulating learners’ activity and interaction with a WBLE according to Information Foraging theory. The basic underlying assumption in our tool is that learners have some information goal and their surfing patterns through the WBLE are guided by information scent. The tool attempts to quantify the concept of information scent, using Latent Semantic Analysis (LSA, Landauer & Dumais, 1997).

LSA was developed to mimic human ability to detect deeper semantic associations among words, phrases or whole sentences. LSA builds a semantic space representing a given user population’s understanding of words sentences, and whole texts from documents that these users are likely to have read. The meaning of a word, sentence or any text is represented as a vector in a high dimensional space, typically with about 300 dimensions. LSA generates the space from a very large collection of documents that are assumed to be representative of a given user population’s reading experiences. The degree of semantic relatedness or similarity between any pair of texts, such as the description of a learner’s goal and a link label on a webpage, is measured by the cosine value between the corresponding two vectors. Each cosine value lies between +1 (identical) and -1 (opposite). Near-zero values represent two unrelated texts. Another important measure provided by LSA is term vector length, a measure that is correlated with word frequency and that estimates how much knowledge about a word or phrase is embedded in the designated LSA semantic space. Words with low frequency in the corpus have short vector lengths.

LSA also served as a computational model of information scent in ACWW, a conceptual artifact based on Cognitive Walkthrough Evaluation (Blackmon, Kitajima, & Polson, 2005) method and the CoLiDES theory. However, despite the fact that the results presented seem to be very promising, lack of integration of useful functions—such as automatic grabbing of links, storage of results, automatic prediction and walkthrough of a user’s path—inspired us to create a more complete and automated tool described briefly in the following.
The main components of the ISEtool architecture are diagrammatically represented in Figure 2. A typical usage scenario of ISEtool is the following: First, the designer defines the profile of the learners by choosing one of the available LSA semantic spaces (e.g. general reading up to first year college). Subsequently, the designer describes a typical learner’s goal in a text box using free text. These typical goals should be acquired by representative users of the targeted learner profiles by means of exploratory methodologies (interviews, surveys etc).

Next, the ISEtool loads the page in its embedded internal browser and parses the page that the designer has defined as the entry point of the learners’ interaction with the WBLE under examination. It collects all available links on the page, it finds and stores link types and type of the pointed file. It also finds and stores the “proximal cue” of each link by grabbing the textual description, if it is a text hyperlink or the alternative text (e.g. ALT tag), if it is a graphical hyperlink. At this point it should be mentioned that in cases of missing alt tags in graphical hyperlinks the user of the tool is notified and asked to optionally enter his description of the image (alternatively he can ask for the learners’ descriptions by means of exploratory methodologies).

Additionally to this, the tool also discriminates automatically the external and internal links. The calculation of information scent for all links is achieved by running in a transparent and automated way, one-to-many analysis of the LSA algorithm (http://lsa.colorado.edu/). LSA computes and returns the semantic similarity (LSA index) of the learner’s goal against all the proximal cues of the links. The calculated information scent for each proximal cue can be also depicted in the internal browser of the tool next to each hyperlink. At a next step the evaluator can use the tool to automatically select the link found to “emit” the higher scent, thus the one with the higher probability to be followed by the simulated learner with the specified goal. Subsequently the tool “visits” the next page and repeats the same process until the designer decides that the user goal is met or that a dead-end has been reached.
The tool offers a number of options to the designer and can be used during the design and evaluation of a WBLE to identify all the aforementioned categories of web page and web site level problems that are caused due to inadequate scent emitted from the proximal cues in the WBLE. The user of the tool can sort the spreadsheet-like link structure produced by the tool according to any column and change the default color coding (e.g. define intervals and color ranges of semantic similarity) adjusting the tool to her needs and preferences, in order to get a better insight of the output. At the same time she can inspect the annotated version of the page under examination in the internal browser so that she can also take into account the layout of the page. Moreover, the tool produces warnings of unfamiliar cues based on the LSA term vector length of each proximal cue, a measure that is correlated with word frequency. When some of the words used in the proximal cues of the links have short term vector lengths (e.g. they have low frequency in the defined corpus) this is a good indication that the learners modeled by the semantic space selected will perceive them to be relatively meaningless and thus they will be incapable of relating them semantically to their goal. At a site level analysis the tool provides at any step of the simulation a graphical visualization of the predicted learner’s path and the scent trail followed. Thus, the designer can identify and investigate further cases of steps in the trail that have low scent (e.g. below a threshold that she defines) or lead the learner to the ‘wrong’ path. Finally, it is worth mentioning that ISEtool also allows exporting the results of the simulation in different formats for further analysis.

In order to present to a greater extent the utility of ISEtool we demonstrate its use by a detailed representative example, shown in Figure 3. In this example an evaluator of a WBLE (OpenCourseWare on critical thinking - http://philosophy.hku.hk/think/) firstly defines the main page of the WBLE as the entry point of interaction, a typical learner information goal and a typical learner profile. Subsequently, the tool automatically parses and analyzes the semantic similarity of all the proximal cues (i.e. links’ descriptions) against the typical learners’ goal and displays the results. At this point, the evaluator notices a warning of the tool for unfamiliar words (e.g. “Sentitial Logic”). These warnings could be translated to strong indications that the learner of the specified profile will probably find meaningless these words and thus will be unable to relate them semantically with her goal. She decides to write down the issue and discuss with the designer for a more appropriate term after she finishes with the evaluation of the WBLE for all the identified learner profiles. Then, she sorts the links by their semantic appropriateness (LSA index) and inspects carefully the output of the tool. She observers that there are some cues that possibly compete for the learners’ attention (e.g. “What is critical thinking? – 0.76, “Argument Analysis” – 0.66, “A mini guide to critical thinking” – 0.60). By taking advantage of the internal browser of the tool she quickly realizes that the most beneficial cue is “Argument Analysis” and the others are possibly classified as competing cues.

At a next step the evaluator uses the tool to ‘follow’ the ‘correct’ cue and repeat the parsing and semantic analysis. This time she also changes the default color coding (i.e defines ranges and colors of semantic similarity) adjusting the tool better to her needs. Subsequently, she realizes that there are again some proximal cues with comparable LSA index but this time she concludes that they all contribute to the learners’ goal and thus she decides not to classify them as competing cues. Next, she uses the tool to ‘follow’ the aforementioned cues and inspect the learners’ predicted path and scent trail followed by taking advantage of the corresponding functionalities
offered by the tool. She notices that the predicted learner’s path is reasonable in terms of depth (i.e. 2 clicks) but suspects that there is a misclassified node problem at a web-site level, since the scent seems to drop, instead of increase, as the learner traverses the predicted path.

Figure 3. A representative example of using ISEtool to analyze a WBLE against a typical learners’ goal
FUTURE TRENDS
Despite the encouraging results obtained using ISEtool, there are still some issues to tackle. For instance, initially when a web page of the WBLE is analyzed, the alternative text (e.g. the ALT Tag) of each graphical-link is assumed to be the proximal cue of this link. Even if all the graphical-links have alternative text, for a learner with a graphical browser the actual proximal cue is the graphic itself. Currently, the adopted solution is to notify the user of the tool for such instances and ask for her descriptions. Additionally to this, there are WBLEs where a set of links is presented in a nested menu-like approach. Thus, the learner primarily focuses on the general description, and spreads the rest of her attention to identify the desired menu subitem, which is anticipated by taking into account the context communicated by the header. At the moment, our tool cannot mimic this behaviour, thus often leading to ‘flat’ or misleading results.

Future work contains conducting studies with real users (e.g. actual learners using various WBLEs), in order to further validate the accuracy of the developed tool. Additionally to this, to study how goal reformulation occurs while learners explore a WBLE towards finding desired patches of information. Finally, to a broader context, to examine possible extensions to the developed model such as data describing learners’ profiles or specific particularities of the learning domain. Further research is needed on the effects of other aspects of the WBLEs, such as credibility and aesthetics and their influence in learner’s motivation and engagement, as well.

Another tool that we envisage is one that automates the card sorting technique by calculating semantic similarity of each web page and clustering accordingly the information space. This tool addresses the problem of reasonable content structuring and helps avoiding the aforementioned web site level problems during the design of a WBLE. Although, card-sorting study results can be stable with 20 or even fewer participants (Tullis & Wood, 2004), a model-based technique could further accelerate the design and evaluation lifecycle of a WBLE. A typical scenario of the tool we envisage is the following: First the designer inputs all the titles of the pages that the WBLE will contain. The tool then runs an automated analysis, using the LSA algorithm and machine learning techniques. LSA is used to calculate the semantic similarity among all the pages, while clustering algorithms are applied to group together semantically similar pages. The output of the tool is the recommended clustering of the pages comprising the learning sections of the WBLE. Specifically, the tool clusters the described information space, suggests how the pages should be distributed and which pages should have links to each other, according to their semantic similarity. A possible variation to the previous scenario could include the definition of the desired number and/or the labels of the learning sections to be created. This variation implements an automated process of a closed card sorting technique where the designer specifies in advance the number and/or the names of the learning sections to be created and the tool places each page to a learning section according to their semantic similarity.

CONCLUSIONS
In this chapter we have described our proposal for design and evaluation of WBLEs that couples efficiently learning models, learning content design and usability requirements based on the notion of information foraging theory. Since the task of finding information related to a specific subject of study in an efficient and effective
manner is of fundamental importance in the frame of WBLEs, we argue that Information Foraging can propel our understanding of the ways learners cope with a complex learning hyperspace. While the supporting value of a coherent learning content architecture scheme to learning activities designed under the influence of behaviouristic pedagogical paradigms is rather straightforward, we argue that even approaches based on a sociocultural view on learning could equally benefit from the application of information foraging theory. In particular we proposed four different ways to have information foraging theory informing the design and evaluation of WBLEs, Directives, to ensure proper learning content structuring and cues with strong scent, tools based on LSA to automate the design and evaluation process, ways to construct archetypal learner’s profiles by combining information foraging theory and user data and learning tools to realise collaborative information filtering and personal information patch creation, thus allowing learners to organize their reference materials in a meaningful and constructive way. Those tools could be also treated as a way to examine learners’ goals, their decision making processes and adaptations to the information access system environment. This knowledge can then be extended and used to develop methodologies and tools that lead both the design and the evaluation process of WBLEs.

Such an example is the InfoScent Evaluator tool (ISEtool) which automatically evaluates semantic appropriateness of the hyperlinks’ descriptions of a complex learning hyperspace. The utility of the tool is twofold. To explore alternative designs and solutions (“what-if” scenarios) and to support formative and summative usability evaluations, reducing the need to involve actual learners which is costly and time-consuming. Initial application of the tool showed promising results, thus further validating our argument that researchers can make use of this knowledge in assessing interaction design of WBLEs.

However, despite the fact that the notion of information foraging seems compatible to the principles of active learning, large scale, real world application of our proposals will greatly serve our effort to better clarify other, possibly unforeseen at the moment, particularities of a WBLE’s design and evaluation lifecycle. Additionally, findings and conclusions from studies of how learners form their goals, what strategies they follow, what criteria they use to evaluate information and how they adapt to the given learning environment, can update existing or form new design and evaluation techniques for web-based educational systems.

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