Semantically connected learning resources fostering intuitive guided learning

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Abstract: If on the one hand the individualised teaching approaches try to find the best sequence of learning resources capable of satisfying individual goals, preferences and contexts, the intuitive guided learning approaches, on the other hand, envisages a non-linear learning experience where each learner can chose a personal path across the material according to his/her interests and preferences. In this paper we present a model, a methodology and a software prototype that is able to combine the advantages of both approaches by introducing the concept of 'compound learning resource': complex didactic artefacts where content is organised in pages and navigation among pages is user-driven. The pages are linked through semantic connections that have a two-fold function: they guide the learners' navigation, and allow the dynamic adaptation of the resource according to learners' needs and preferences (individualisation). Experimental results with real users in a university context are also presented as well as a comparison with similar systems.

Keywords: individualised teaching; typed links; intuitive guided learning; semantic link networks.

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1 Introduction

It frequently happens that the complex nature of a course prevents teachers from easily finding a correct, fluid and comprehensive sequence of learning resources able to fit whatever learners' need. This can be due to a shortage of learner's mental structures (arising from a lack of knowledge about concepts that are object of teaching or their prerequisites) or owing to their own learning style. This may result is an inefficient learning experience.

The problem can be overcome through the adoption of *individualised teaching* approaches which see the learning as a 'journey' that may be different for each learner. Such approaches are aimed at selecting the best sequence of learning activities a learner must perform to reach a given learning goal, taking into account his/her capabilities, knowledge and preferences. The individualised teaching is used for developing personal learning programmes and for engaging learners in the learning process so that learners' learning potential and success can be optimised. Unfortunately it tends to 'force' the learner to follow a fixed, optimised, sequence of activities allowing few crossing possibilities (Fok and Ip, 2004).

The *intuitive guided learning* approaches try to solve this same problem but in a different way. Instead of forcing the learners in a particular course of action, they configure the surrounding pedagogic design in order to guide them towards learning objectives in an unobtrusive fashion. One of the most important characteristics of such a pedagogy is that the experience is non-linear: in fact 'guided' (as an antonym of 'forced') implies that the learner can deviate from the intended path through the learning experience (Mott et al., 2006).

The intuitive guided learning approaches are particularly suitable for *digital natives* that consider this modality of interaction to be more natural and stimulating than sequential reading. They are typically curious and driven by the pleasure of discovering something new within the learning material. In these learners, learning happens incidentally, through the exploration and the finding of a personal key of content understanding (Calvani and Rotta, 1999).

The purpose of this paper is to define a method that tries to combine the advantages of both individualisation and intuitive guided learning. The defined method is able to generate optimised, non-linear learning experiences that can support multi-perspective learning by discovery but, at the same time, are individualised on each learner.

To this aim we introduce the concept of 'compound learning resource (CLR)': a complex didactic artefact that brings together multiple semantically connected resources that may be browsed in different ways. Semantic connections guide the learner during the resource navigation providing hints about what he/she will see next. According to Rotta et al. (2000), this improves the navigation effectiveness. Semantic connections are also used to adapt CLRs with respect to teaching and learning preferences, i.e., to create different views of the same resources to suit different needs. According to Rotta and Hadwin (2005), this enables to balance *scaffolding* (i.e., the adoption of specific 'structures' in the form of 'interpretation keys' to follow) and *fading* (i.e., the decrease in using such structures when the learner shows a greater autonomy).

Figure 1 (a) Differences between individualised learning (b) Intuitive guided learning (c) The proposed approach (see online version for colours)

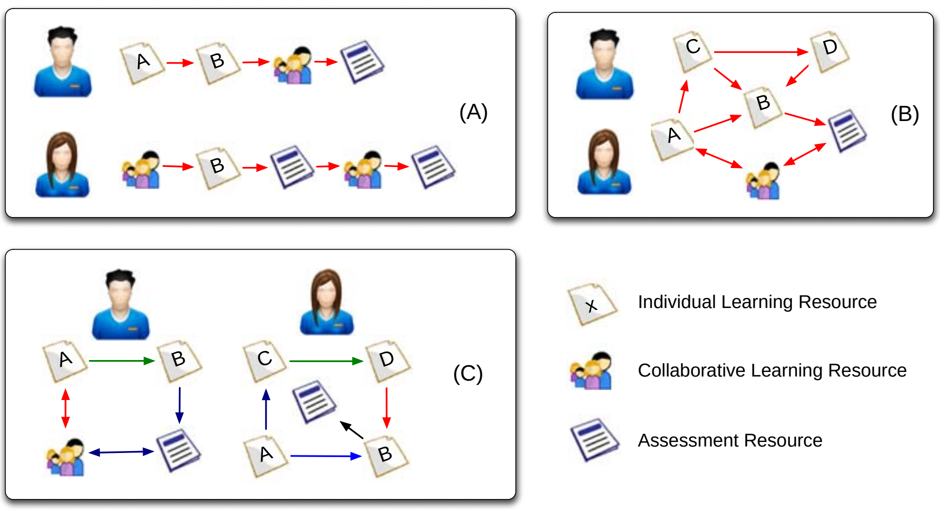


Figure 1 explains the three approaches with a visual example, involving two users and several individual and group activities. The box (a) shows an example of individualised teaching: to reach the same goal, two learners have to follow two different optimised sequences of learning activities. The box (b) shows an example of intuitive-guided learning: to reach the same learning goal, the two learners access a common set of connected learning resources. Each learner is not forced in a specific sequence and is free to discover his/her own path by following provided connections (arrows).

The box (c) shows an example of the approach we propose. As in the intuitive-guided learning, a learner can browse a set of connected learning resources. As in the individualised teaching, each learner is provided with an optimised set of activities and connections. Moreover, the connections are semantically described (different colours) in order to provide guidance to the learner during the learning experience.

The paper is organised as follows: the second section introduces some existing works related to this research, the third section describes the starting point of our research: the IWT individualised learning system (Adorni et al., 2010); the fourth section presents the proposed approach from the theoretical point of view, the fifth section presents the developed prototype whose experimentation with real users is summarised in the sixth section. The sixth section also includes a comparison with similar systems, while the last section presents conclusions and planned future works.

2 Related work

A *typed hyperlink* (Sicilia et al., 2004) in a hypertext system is a link to another document or part of a document that includes information about the character of the link. This allows a user to take actions such as searching only certain types of links or displaying them differently.

Typed links were a common feature in pre-internet hypertext systems but the lack of standardisation has always hindered their use beyond prototype systems. The version 4 of the HTML standard supports typed links using the *rel* (forward) and *rev* (reverse) attributes to <*link*> and <*a*> tags.

In Zhuge (2007) a Semantic Link Network (SLN) is defined as a directed network consisting of nodes and semantic links. A node can be a concept, an instance of concept, a schema of data set, a URL or any form of resource. A semantic link reflects a kind of relational knowledge represented as a pointer with a tag describing such semantic relations as *equal*, *causeEffect*, *implication*, *subtype*, *similar*, *instance*, *sequence* and *reference*.

Compared with the typical hyperlink structure, typed links have several advantages in supporting e-learning because they foster inductive and analogical reasoning, help to understand new semantic relations and can inspire creative thinking and broaden the learners knowledge.

Typed hyperlinks between learning resources find their motivation in the theory of *Ausubel* (1968) and on the distinction between learning ‘by rote’ and learning meaningfully. When we learn by rote, we relate new ideas in cognitive structures with existing ones without effort. In contrast, when we learn meaningfully, we have to integrate new concepts in specific ways with ideas and propositions already existing in our cognitive structures.

In the latter case, typed hyperlinks are able to drive and support the learning. These relations can act as advance organisers to facilitate the integration of new concepts and ideas with the relevant existing knowledge (McManus, 2000). In this way, it is possible to obtain a correct ‘learning behaviour’ from the learner, which put him/her in such a position to achieve the learning goals in a controlled and directed way.

A first list of relations between learning resources is proposed by *Dublin Core* (2012) for the annotation of digital resources and is integrated in the IEEE LOM standard (2002) for the annotation of learning objects. This standard proposes the following 6 relations (including reverses): *hasVersion*, *Replaces*, *Requires*, *hasPart*, *References* and *hasFormat*. The semantics of these relations, not formally specified within the LOM standard, has been clarified and connected to well known ontologies in Rodriguez et al. (2009).

Further studies extend these standard relations from the pedagogical viewpoint. As an example, the *Educational Rationale Metadata Initiative* (Carey et al., 2002) has defined metadata to represent process-oriented information about instructional approaches for learning resources.

An adaptive hypermedia system is a system able to adapt the presentation of content or links based on the user model. Two major technologies in adaptive hypermedia can be distinguished: adaptive presentation and adaptive navigation support (Brusilovsky, 2012). The first adapts either the content of a document or the style of the text. The second concentrates on changing the presentation of links. The most popular area of adaptive hypermedia research is the educational hypermedia, in which the study of the courseware on a particular subject is the student’s goal.

Several adaptive educational hypermedia systems exist that exploit hyperlink adaptation (Kubeš, 2007). As an example, the *AHA!* System employs fragment and link hiding to adapt courses. *INSPIRE* offers instead adaptive link annotation and sorting as well as adaptive curriculum sequencing techniques to guide the learner through a learning space using a path respecting his learning style.

InterBook is a tool for the creation and presentation of adaptive electronic textbooks. It offers adaptive link annotation and direct guidance as well as automatically generated glossaries and indexes. *NetCoach* simplifies the course authoring process by offering the possibility to insert content and define relations between documents using concept networks. Adaptive annotation of links and curriculum sequencing features are also supported.

ALE is an environment for creating adaptive courses. It tracks students’ progress through the course and annotates links using this information. *Knowledge Sea* tries to help students with navigation to additional external content by providing adaptively annotated links based on topics and recommendations from other students.

MetaLinks is a system for creating adaptive electronic textbooks. The system monitors a student’s path through the content and provides adaptive annotation of links advising the student whether all prerequisites for a given page have been met or not. *QuizGuide* helps students to select the most relevant examples through adaptive annotation to links to problems. Links are annotated on the basis of known prerequisites and relevance of the current topic.

Differently from other approaches to adaptive e-learning, the adaptive educational hypermedia systems are able, in principle, to provide both individualised teaching and intuitive guided learning. Nevertheless, as we will examine in Section 6, some existing systems and prototypes focus their attention on providing links that are relevant for a given the learner only basing on the knowledge acquired by them, disregarding all learning preferences. Moreover, many of the existing systems do not use semantic connections so they are not able to add any explanation to the proposed links. The approach here presented tries to overcome both these limitations.

Another problem of the current generation of adaptive educational hypermedia is their architecture since most of them do not support typical functions of a modern learning management system (Bozic et al., 2012). Therefore only a few of them are actually being used for teaching real courses. In short, while providing a rich set of tools, many of today's successful LMSs do not offer enough personalisation and adaptation. On the other hand, adaptive educational hypermedia systems have the techniques for adaptation but show the lack of availability of standard tools. This is another issue that we try to solve with our approach.

3 The starting point

The starting point of this research is intelligent web teacher (IWT) (Adorni et al., 2010), a complete e-learning system based on individualisation principles. IWT can generate personalised learning experiences by relaying on four interacting models as described below (Capuano et al., 2008).

The *domain model* describes the knowledge that is object of teaching through a set of concepts and a set of relations between concepts. Teaching preferences can be added to the domain model to define feasible teaching strategies that may be applied for available concepts. The *learner model* represents a learner through a cognitive state that measures the knowledge reached by him/her at a given time and by a set of learning preferences that provide an evaluation of which learning strategies are more feasible for him/her. Both components are automatically assessed by IWT, by analysing results of testing activities and the learner's behaviour during the learning experience (Capuano et al., 2008).

The *learning resource model* represents a learning resource through feasible metadata respecting the IEEE LOM standard. It includes the set of concepts that are covered by the learning resource and a set of didactical properties representing learning strategies applied by the learning resource. The *unit of learning model* represents a sequence of learning resources needed by a learner in order to understand a set of target concepts in a given domain. A set of teaching preferences can be linked to this model to define feasible teaching strategies that should be applied within it.

In Capuano et al. (2009) we have described the generation of a unit of learning starting from a set of target concepts and from a learner model. The process generates a feasible sequence of domain concepts able to teach the target concepts. Then it removes domain concepts already known by the target learner by looking at his/her cognitive state. Eventually, it associates the best matching learning resources to each remaining concept, taking into account teaching and learning preferences.

By leveraging on these models, IWT supports a learner centred approach and is able to build the best sequence of learning resources for each learner starting from a given set of target concepts (Mangione et al., 2009). In the next section, we describe how we succeeded to enrich these functions by adding intuitive guided learning capabilities.

4 The proposed approach

CLRs are structured as dynamic hypertexts where the content is organised in several multimedia components and navigation among components is user-driven. The CLR is capable of supporting both individualised teaching and intuitive guided learning thanks to embedded semantic connections and algorithms working on the adaptation of such connections (Capuano et al., 2012b).

Connections can link a satellite component to a kernel and learning resources together. To this purpose we have defined a *semantic connection model* describing each element of a connection as well as a predefined set of meaningful connections. The connections can be dynamically and automatically activated and deactivated basing on teaching and learning preferences. To this aim we have also defined a *CLR adaptation methodology*.

In order to adapt connections also when no preferences are available for a given user, we have defined a *CLR initialisation methodology* based on recommender systems' principles. The following subsections describe in more detail all these elements.

4.1 The semantic connection model

The semantic connections are able to drive and support the learning, they can work as advance organisers because they facilitate the integration of new concepts and ideas with the relevant existing knowledge. To formally define the meaning of a connection, we have defined a *semantic connection type* as a list of four parameters *(name*, *group*, *colour*, *description*) whose meaning is described in Table 1. An extensible *vocabulary* of semantic connection types is centrally defined within the system.

Table 1 Components of a semantic connection type

Name	*Description*
Name	It specifies a unique meaningful identifier for the connection type.
Group	It specifies the group the connection type belongs to. Two groups are defined: connections between and within learning resources.
Colour	It is the colour associated with the connection, once defined the colour of a connection type, it remains the same for all existing CLRs.
Description	It is a textual description of the semantic connection explaining its meaning both to teachers that want to use it in CLRs and to students that can find it inside a CLR and want to decide if to follow it or not.

Table 2 Components of the semantic connection model

Name	*Description*
Type	It specifies the nature of the connection among pages, it refers to a *name* of a semantic connection type as described in Table 1.
Source	It specifies the resource page in R_p from which a connection starts.
Scope	It specifies the part of page text on which the connection applies. If left blank the connection applies to the whole page.
Target	It is the resource page to be shown when the connection is followed by the learner among those included in R_p.
Optionality	It specifies if a connection is optional or mandatory. Only optional connections can be removed by the *CLR adaptation methodology*.
Tooltip	It is a text purposed to provide a brief description of the connected content and is shown to the learner when he/she places the mouse pointer over the connection activator.

We have then defined a *CLR model* as a set of components (named *resource pages*)R_p and a set of *semantic connections* S_c between pages. A resource page belonging to R_p can be a hypertext page created or uploaded by the teacher, any kind of file (e.g., an image, a video clip, a PDF file, etc.) that can be rendered in a web browser, a pointer to an external web page; a pointer to another learning resource belonging to the IWT repository (excluding CLRs). A semantic connection included in S_c is instead represented as a list of six parameters whose meaning is summarised in Table 2.

According to the IEEE LOM standard, the *relation* field of the metadata connected to any *resource page* is used to store information about semantic connections that applies to the page. An application profile extending this LOM field has been created to store not only the connection *type* and the *target* (mapped respectively on the subfields *relation.kind* and *relation.resource* of LOM) but also the other subfields needed by our model. The scope of the *type* subfield has been also extended to take values from the defined vocabulary of semantic connection types.

A further metadata has been used to represent the whole CLR referring (through the standard *has part* relation) to any component page. To specify the compound nature of the CLR, the *general.structure* subfield has been settled to *networked*.

As described by the scope parameter, connections can be applied to the whole resource (page connections) or to pieces of it (text connections). While page connections refer to the whole page of the resource and are shown as coloured boxes (or icons) on the right side of the page (see Figure 5), text connections refer to parts of the document and are represented by highlighting the text where the connection applies (see Figure 5).

Concerning the semantic connection type, as reported in Section 2, several studies exist about connections between digital resources in general, as well as between learning resources. Starting from the analysis of these studies, we selected meaningful connections and included them in two predefined groups: *connections between learning resources* which are purposed to link any kind of resource page with another learning resource from the IWT repository; *connections within a learning resource*, which are internal to the CLR and purposed to link two resource pages (none of them being a pointer to another learning resource).

Table 3 Connections within learning resources

Name	*Description*
Motivation	The referenced content strongly motivates and justifies the importance of the topic explained in the described resource or in a part of it.
Critique	The referenced content presents a critical review of the issues included in the described resource or in a part of it.
Collaboration	The referenced content includes areas for discussion or cooperation about the topic explained within the described resource or a part of it.
Engaging	The referenced content leads students to discover the validity of what they are studying by displaying bad behaviours held by those who do not know the topic explained within a resource or a part of it.
Integration	The referenced content is purposed to deepen (from several viewpoints) the theme explained in the described resource or in a part of it.
Anchor	The referenced content is purposed to anchor the knowledge explained in the described resource (or in a part of it) within an authentic context.
Perspective	The referenced content explains the knowledge provided by the described resource (or by a part of it) from a different perspective.

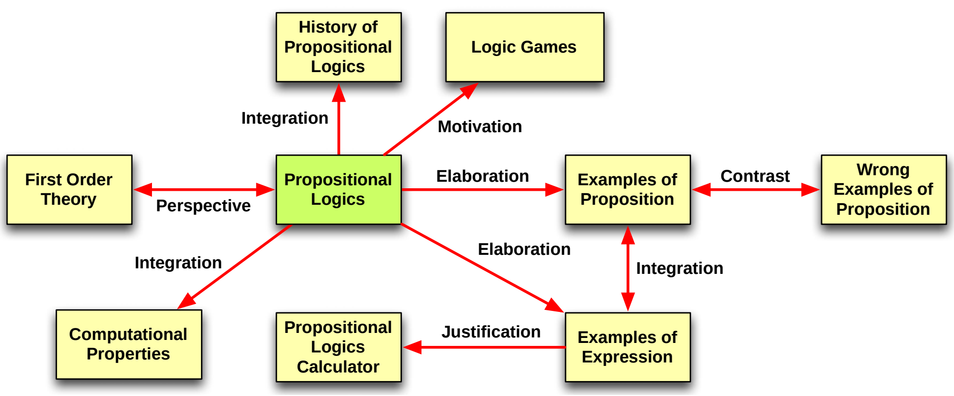
The connections within a learning resource are generally purposed to enhance the educational intentions underlying the architecture of a learning resource. Several studies can guide to the identification of feasible typologies for this kind of connections. In particular we started from the *Theory of Conditions of Learning* (Gagné, 1985) and mixed tags from the *Educational Rationale Metadata Initiative* (Carey et al., 2002) to obtain the list of connection types reported in Table 3.

Moreover, by exploiting results coming from the *Rhetorical Structure Theory* (Mann and Thomson, 1987) that have been used also for *Learning Objects Networks* (Madhour et al., 2006) we have also proposed a list connection between learning resources reported in Table 4. The CLR obtained through the application of the defined semantic connections model has a graph-like structure as shown in Figure 2.

Table 4 Connections between learning resources

Name	*Description*
Elaboration	The referenced resource elaborates the content of the described resource or of a part of it.
Evidence	The referenced resource provides information to increase the belief in the claim mentioned in the described resource or in a part of it.
Interpretation	The referenced resource interprets or explains the described resource or a part of it.
Justification	The referenced resource justifies the described resource or a part of it.
Summary	The referenced resource summarises the described resource or a part of it.
Contrast-opposite	The content of the described resource (or a part of it) and of the referenced resource are opposites.
Condition-restriction	The referenced resource limits the content of the described resource or of a part of it.
Restatement-alternative	The referenced resource provides an alternative for the presentation of the described resource or a part of it.
Sequence	The referenced resource is the sequence or chronology of the described resource.

Figure 2 The structure of a CLR (see online version for colours)



In Figure 2, the structure of a CLR on propositional logics is presented. The navigation starts from a kernel page (*propositional logics*) explaining the main concepts connected to this topic. Students that may want to deepen specific sub-topics can follow the available *integration* connections leading to a resource about the *history of propositional logics* and to another one about the *computational properties* of propositional logics.

Students showing little interest in the explained topics can follow a *motivation* connection leading to a page including several *logic games* that are based on the concrete application of the propositional logics. To elaborate the concepts acquired within the kernel resource, moreover, the student can follow an *elaboration* connection to some provided *examples of proposition* and *examples of expression* connected to the kernel resource. From each set of examples the student can reach the other one by following an *integration* link.

While reading the examples of proposition, the student can reach another page showing *wrong examples of proposition* by following a *contrast* connection. While reading the examples of expression, he/she can reach, by following a *justification* connection, an interactive *propositional logics calculator* allowing him/her to express and calculate the 'truth value' of any specified expression. Finally, to see the same topic from a mathematical perspective, the learner can follow a *perspective* connection linking to a resource about *first order theory*.

4.2 CLR adaptation methodology

The semantic connections in CLRs can be automatically hidden with respect to teaching and learning preferences. As described above, in IWT teaching preferences are linked to the unit of learning model in order to define feasible teaching strategies for it. They are represented as an application TP ($Props \times PropVals$) $\rightarrow$ [0, 10] where $Props$ is a set of didactical properties and $PropVals$ is the set of feasible values for such properties. IWT teaching properties and related feasible values are reported in Table 5. As it can be seen, they constitute a subset of IEEE LOM standard fields.

Table 5 Teaching and learning properties and feasible values

Properties	*Feasible values*
Didactic method	Deductive, inductive, etc.
Resource type	Text reading, video clip, simulation, virtual experiment, etc.
Interactivity level	Low, medium, high
Age range	0–5, 6–10, 11–13, 14–18, 19–24, 25+
Language	English, Italian, Spanish, German, etc.
Semantic density	Low, medium, high
Interactivity type	Active, expositive, mixed
Difficulty	Easy, medium, difficult

To support CLR adaptation, a new property is added named 'allowed connections' or *all-conn* whose feasible values are those reported in Table 3 and Table 4. Allowed connections for a unit of learning can be so specified by the teachers during the course design.

As described above, in IWT the learning preferences are linked to the learner model to evaluate learning strategies that may be adopted for a learner. They are represented as an application *LP* (*Props*×*PropVals*) → [0, 10] where *Props* and *PropVals* have the same meaning as the one said before.

To support the CLR adaptation, a new kind of property is added named 'preferred connections' or *pref-conn* whose admitted values are those reported in Table 3 and Table 4. Preferred connections for a given learner will be inferred by the system through an algorithm that analyses his/her behaviour during the CLR navigation.

First of all, when a new learner model is created, the value of *LP* (*pref-conn*, *c-type*) is initialised to 5 for each type of connection *c-type* (i.e., for each value reported in Table 3 and Table 4). This means that, initially, all connections are equally preferred. Then, each time a learner completes a CLR, a modifier $mod_{c\text{-}type}$ is calculated for each *c-type* for which at least a connection in the resource exists:

$$mod_{c-type} = \frac{\sum_{c \in conn-type} toggle_c}{|conn-type| \cdot counter}$$

where *conn-type* is the set of resource connection whose type is *c-type*, $toggle_c = 1$ if the connection *c* has been followed by the learner and -1 otherwise and *counter* is the number of times the user has accessed this CLR until current verification.

This means that each time a learner follows a connection, the preference for the related type is increased, while each time an existing connection is skipped, preferences for the related type are decreased. The level of increase/decrease depends on the number of connections of that type, that are available in the resource, as well as on the number of times the learner accesses a learning resource (i.e., connections accessed the first time produce greater modifications with respect to the following accesses).

Once the modifier is calculated for all connection types after a CLR fruition, the new value for *LP* (*pref-conn*, *c-type*) is then calculated in this way:

$$\max\left\{\min\left\{LP(pref\text{-}conn, c\text{-}type) + mod_{c\text{-}type}, 10\right\}, 0\right\}$$

so adding the modifiers to the learning preferences of the learner model but limiting the result between 0 and 10. By knowing *LP* and *TP* for each available connection type it is possible to apply a CLR adaptation algorithm working in this way:

- remove any optional connections of type *c-type* if *TP* (*all-conn*, *c-type*) $<\theta_1$
- remove any optional connections of type *c-type* if *LP* (*pref-conn*, *c-type*) $<\theta_2$
- reorder page connections following the decreasing order of *LP* (*pref-conn*, *c-type*).

Constants θ_1 and θ_2 range from 0 to 10 and are settled experimentally. The algorithm is executed each time a resource is accessed by the learner. In fact, while function *TP* does not change for a given course, *LP* may change throughout the course according to the learner's behaviour.

4.3 CLR initialisation methodology

As stated in 4.2, the learning preferences, for a new student, are initialised by settling the function *LP* ('preferred connections', *c-type*) = 5 for each type of connection *c-type*. This means that, initially, all connections types are equally preferred by any student. In order to improve this generalisation, we defined an algorithm, based on recommender systems' principles, to initialise these values taking into account preferences of similar users.

An extensive state of the art about recommender systems has been provided in Capuano et al. (2012a). In our case we chose to combine a cognitive approach with a collaborative one: as in the collaborative approaches, we approximate unknown values of a utility function (in our case the preference of a learner for a given connection type) from those made available by people considered similar to it. According to cognitive approaches, similarities are considered starting from the knowledge about learners maintained in learner profiles.

By indicating with *u*(*l*, *c-type*) the preference of the learner *l* for the connection *c-type*, i.e., by settling *u*(*l*, *c-type*) = *LP* ('preferred connections', *c-type*), we can determine unknown values for *u*(*l*, *c-type*) for a learner *l* by aggregating the utilities expressed for *c-type* by users similar to *l* with the following equation:

$$u(l, c\text{-}type) = \frac{\sum_{l' \in L'} u(l', c\text{-}type) \cdot sim(l, l')}{\sum_{l' \in L'} |sim(l, l')|}$$

where *L*' is the set of *n* learners considered most similar to *l* (with *n* chosen between 1 and the total number of system learners) and *sim*(*l*, *l*') is a measure of similarity between the learner*l* and the learner *l*'.

The similarity between two learners can be calculated using similarity measures such as the cosine similarity or the Pearson's correlation coefficient (Capuano et al., 2012a). These measures are applied to the vectors $l = (w_{1,1}, \ldots, w_{1,n}, \ldots w_{m,1}, \ldots, w_{m,n})$ that characterise the learners, where each vector component $w_{i,j} = LP\ (Prop_i, PropValue_j)$, i.e., the preference value connected to the *i*-th property and the *j*-th property value with respect the learning preferences reported in Table 5, so excluding the new introduced property 'preferred connections'.

To apply this recommendation component, the preferred connections are not initialised and remain undefined until a CLR is reached by the student. Before entering the first CLR, only preferences related to connections used by the resource are initialised by applying the preceding equation. Once initialised, the connection preferences are further modified according to the learner's behaviour by applying the algorithm defined in Section 4.2.

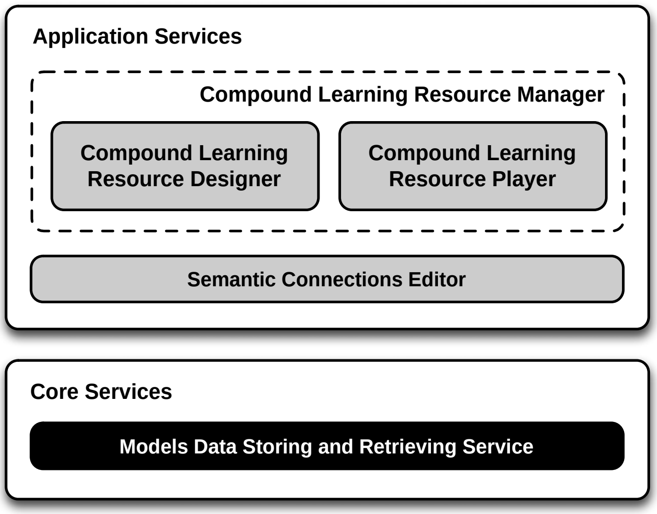
5 The developed prototype

As reported in Section 3, the starting point of our research is the IWT e-learning system. Its logical architecture (Capuano et al., 2011) is divided into four main layers. The first layer is the *framework* used by developers to design and implement other IWT components. The second layer is composed of *core services* providing basic features for the management of users, roles, resources, metadata and domains as well as for user profiling and individualisation.

The third layer is composed of *application services* used as building blocks to compose e-learning applications for specific domains. They include blocks for content management, learning and ontology management as well as for communication and collaboration. On the top of the stack, *learning applications,* covering specific scenarios obtained as integration of application services, are built.

The IWT server side components are developed in .NET technology and use Microsoft SQL Server for persistency. IWT is an extensible system both at the level of learning resources (with drivers, i.e., software components able to edit, manage and deliver a specific type of resource) and at services level (with plug-ins, i.e., software components providing new back-end services). To integrate CLRs in IWT a set of additional components have been designed and developed as depicted in Figure 3.

Figure 3 Developed components within the IWT architecture

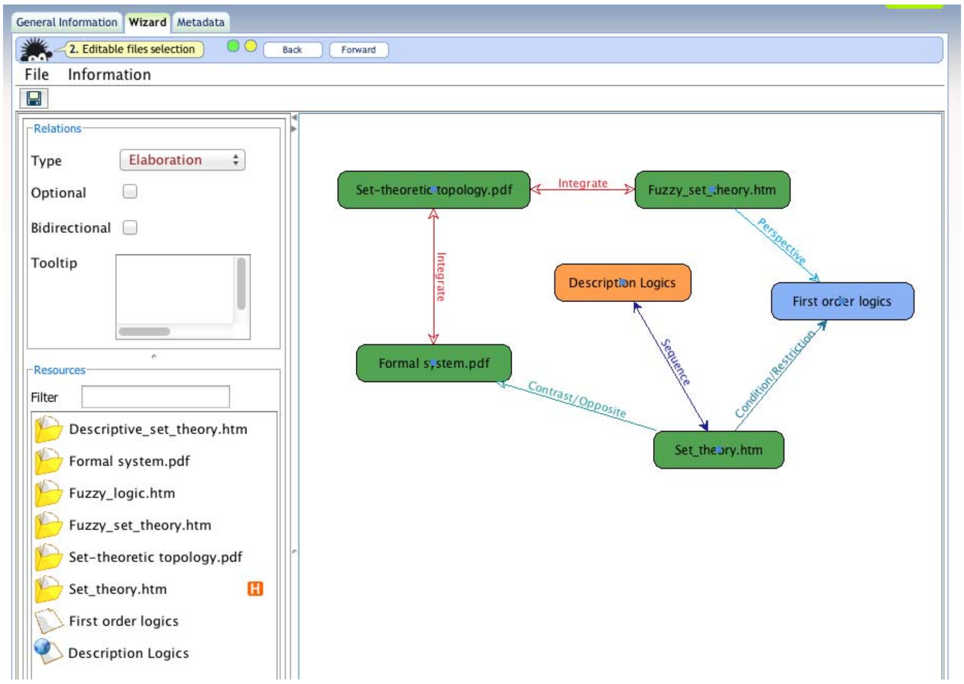


As shown in the figure, we extended existing models' storing and retrieving services to support the semantic connection model defined in 4.1. Also data structures for learning and teaching preferences have been extended to add preferences about semantic connections. Within the *application services* layer, we then implemented and integrated a *CLR Manager* dealing with the design and the execution of CLRs. Such component is composed of two sub-components: a designer and a player.

The *designer component* allows the teachers to author CLRs according to the model defined in 4.1. Within the designer the teacher can create resource pages through a WYSIWYG editor, can upload any kind of additional file (images, video clips, texts, etc.), can import external web pages as well as learning resources belonging to the IWT repository. Then he/she can define semantic connections among selected pages through the interface shown in Figure 4.

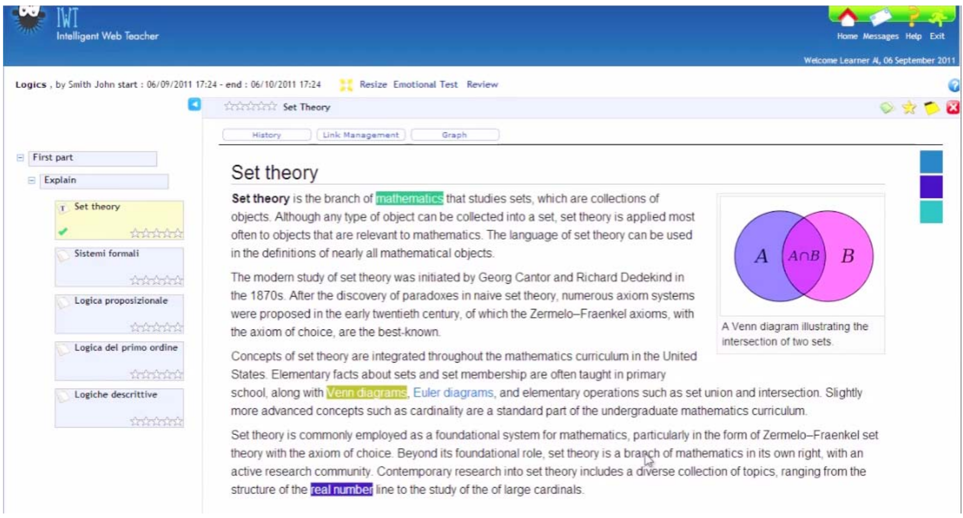
Available pages are listed on the left, divided according to the typology (HTML, file, URL, resource). The teacher can drag pages from the left and put them in the workspace. Then he/she can define connections among pages and define, for each connection, the value of parameters defined in 4.1. A separate interface, accessible by system administrators, allows to define new connection types as defined in 4.1.

Figure 4 User interface of the CLR designer (see online version for colours)



The *player component* allows learners to execute a CLR and implements both the adaptation algorithm defined in 4.2 and the initialisation one defined in 4.3. Figure 5 shows the player embedded within an IWT unit of learning whose sequence of learning resources to follow is represented on the left side. The learners start the navigation from an index page and may follow connections between and within the resource.

Figure 5 The CLR player embedded in IWT (see online version for colours)



The parts of text that activate a connection are highlighted in different colours according to the connection type. The page connections appear on a vertical bar on the right side of the resource as coloured boxes (colour is chosen according to the connection type). Both categories of connections are adapted at the beginning according to the algorithms described in Section 4.

When a page differs from the index, a back connection (shaped a coloured triangle) is added to the right side bar in order to navigate the connection backward. Once a learner puts the cursor over the highlighted text or a coloured box, a textbox appears indicating the type of connection and showing the tooltip text defined by the teacher.

6 Prototype evaluation

In this section we provide an evaluation of theoretical and technological components we have defined in this research. Two points of view are considered, functions and effectiveness: functions are evaluated against similar systems while the effectiveness is evaluated through an experimentation made with real users. The results of these two analyses are reported below.

6.1 Comparison with similar systems

The prototype obtained in this research can be compared with other adaptive e-learning systems that provide automatic page link annotation as those surveyed in Section 2. The Table 6 reports a synthesis of this comparison.

Table 6 Comparison with similar systems

System	*Status*	*Semantics on:*		*Link annotation based on:*	
		Pages	*Links*	*Knowledge*	*Preferences*
AHA!	Full system	Yes		Yes	
INSPIRE	Full system	Yes		Yes	Yes
InterBook	Full system	Yes		Yes	
NetCoach	Full system	Yes		Yes	
ALE	Prototype	Yes		Yes	
Knowledge Sea	Prototype		Yes		Yes
MetaLinks	Prototype	Yes	Yes	Yes	
NavEx	Prototype	Yes		Yes	
QuizGuide	Prototype	Yes		Yes	
OUR SYSTEM	Prototype	YES	YES	YES	YES

As it can be seen, the majority of surveyed systems adapt the links basing on learner's knowledge, i.e., links that are not feasible or relevant for a learner given his/her current knowledge of domain concepts are removed or identified with specific colours or icons. Only two systems show or remove links also basing on preferences. Information about previous learner's knowledge is also used for course adaptation basing on standard IWT adaptation features.

Link adaptation, in the greatest part of surveyed existing systems, is based on semantic information connected with the pages composing the learning resource or the learning course. One exception is Knowledge Sea that, being based on external resources, connects semantics only to links to such resources. Another exception is given by MetaLink that uses typed connections like ‘related concepts’, ‘historical background’, etc. The solution we propose is one of the few connecting semantics both to pages and links and using a comprehensive set of link typologies.

6.2 Experimentation with real users

In order to evaluate the effectiveness of CLRs and analyse their effects in the learning process, we involved68 University students enrolled in an online course about *Software Engineering* where one topic, *requirements*, was modelled both with a standard lesson and with a CLR.

All students had to follow the online teaching plan, learn the mandatory material and perform planned learning activities. Concerning the *Requirements* topic, students had the possibility to choose between learning through the standard lesson or through a CLR. Students selecting the second option had to fill a questionnaire to be submitted at the end of the experiment.

As the study was focused on possible improvements to be made on CLRs, the questionnaire was aimed at evaluating both students’ satisfaction and system user-friendliness. In particular, open and closed questions were used to evaluate students’ satisfaction while the system usability scale (Brooke, 1996), based on answers given on the 5-point *Likert* scale, was used to measure user-friendliness.

Concerning students’ *satisfaction*, after calculating the 0-10 scale for each student we got an average of 6.59 (SD = 2.17, Md = 7). This result is very good considering that the CLR-type resources are still in research evolution. Students in general liked CRLs and semantic connections. They found these very useful for their study (M = 7.08, SD = 2.87, Md = 8.5). Most of them (above 75%) indicated that the semantic connections allowed them to go deeper and faster into additional information without having to search for this extra information by themselves.

The average obtained score for *usability* was 60,78 on a scale ranging from 0 to 100. This is not very high but quite promising considering that the tool is still in a prototypal stage. Despite that, many students found the CLR easy to use (M = 3.44, SD = 1.00) and most of them learned to use CLRs very quickly.

Table 7 Summary of experimentation results

	Experimental group	*Control group*
Participants	41	27
Overall satisfaction	M = 6.59, SD = 2.17, Md = 7	
Questionnaire (range: 0–10)		
Usability	60.78	
SUS score (range: 0–100)		
Student performances	M = 7.83, SD = 0.78, Md = 8	M = 6.33, SD = 1.28, Md = 6
Assessment (range: 0–10)		

All students participating in the experiment were also tested at the end of the course with respect to all course topics, including *Requirements*. Obtained scores were then compared with scores gained by students who had not participated in the experiment (control group). The assessment was performed by a lecturer who used a standard 10-point scale to score the students' answers. As reported in Table 7, students from the experimental group scored higher than the control group. Interestingly, the standard deviation (SD) in the experimental group is considerately lower than in the control group.

In summary we conclude that, even if some work remains to be done in order to improve their usability, students liked CLRs and found them interesting to extend their learning by means of semantic connections. In addition, the levels of competences acquired by using a CLR, denoted that the use of semantic connections within the resource contributed to improve the understanding of course key concepts.

7 Conclusions and future work

This paper describes a research aimed at the definition of CLRs: type of learning resources that tries to combine the advantages of individualisation as well as intuitive guided learning. The CLRs are optimised, non-linear learning resources that can support multi-perspective learning by discovery but, at the same time, are individualised with respect to preferences of each learner.

To support CLRs, we defined a semantic connection model and a CLR adaptation algorithm. Basing on such theoretical components, we developed a prototype CLR designer and player tools, and integrated them in an existing e-learning system. We then experimented such system, including CLRs, with real users within an online University course obtaining promising results.

Starting from experimentation results, from the technological point of view, our future work will focus on the provisioning of a more user friendly interface both to students (during the delivery phase) and to teachers (in the authoring phase).

From the theoretical point of view, we envisage some improvement in the semantic connections model with a rationalisation of supported connections exploiting teachers' feedback. The use of a formal language (like OWL) to represent the taxonomy of allowed connections is also envisaged, as well as the connection with concepts defined within some external ontology (Rodriguez et al., 2009).

The described CLR adaptation methodology only relies on learning preferences. The possibility to also use the information included in the available IWT cognitive state (see Section 3) to customise connections for a given user (e.g., to show integrations of a CLR or elaborations around a given topic only when the learner has a sufficient background to understand them) will be investigated.

The possibility to let teachers work at different granularity levels by composing CLRs in more complex structures will be also explored. To do that, a study on how to inherit connections in case of a CLR is used as a component will be performed.

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