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Designing learner-controlled educational interactions based on learning/cognitive style and learner behaviour

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Abstract

Recently, research in individual differences and in particular, learning and cognitive style, has been used as a basis to consider learner preferences in a web-based educational context. Modelling style in a web-based learning environment demands that developers build a specific framework describing how to design a variety of options for learners with different approaches to learning. In this paper two representative examples of educational systems, Flexi-OLM and INSPIRE, that provide learners a variety of options designed according to specific style categorisations, are presented. Experimental results from two empirical studies performed on the systems to investigate learners' learning and cognitive style, and preferences during interaction, are described. It was found that learners do have a preference regarding their interaction, but no obvious link between style and approaches offered, was detected. Derived from an examination of this experimental data, we suggest that while style information can be used to inform the design of learning environments that accommodate learners' individual differences, it would be wise to recommend interactions based on learners' behaviour. Learning environments should allow learners or learners' interaction behaviour to select or trigger the appropriate approach for

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the particular learner in the specific context. Alternative approaches towards these directions are also discussed.

Keywords: Individual differences; Learning style; Cognitive style; Adaptive educational systems; Adaptation; Personalisation; Learner control

1. Introduction

Adaptive learning environments typically model a learner's understanding of a domain according to, for example, their answers to questions or their navigation through the content. This 'learner model' is used in conjunction with a model of the target domain to enable an educational system to adapt the interaction to suit the learning needs of the individual student. Such adaptation usually involves individualisation of one or more of the following: topic presented, questions/problems asked, sequencing of material, navigation recommendations, feedback given. There are potentially many other attributes besides knowledge or understanding that could be modelled in addition, to facilitate an educational interaction, such as motivation, learning goals and learning preferences. Recently, such attributes and especially learning preferences, have attracted considerable attention.

Much research has been undertaken on the impact of different styles on learners' preferences and human learning in general (Riding and Rayner, 1998; Entwistle, 1981; Schmeck, 1988; Kolb, 1984; Keefe, 1979). Style in educational psychology has been recognised as a key construct in the area of individual differences in learning. *Cognitive style* refers to an individual's method of processing information. The key elements in an individual's personal psychology which are structured and organised by an individual's cognitive style are affect or feeling, behaviour or doing, and cognition or knowing, and this psychological process is reflected in the way that the person builds a generalised approach to learning (Riding and Rayner, 1998). The building up of a repertoire of learning strategies that combine with cognitive style, contribute to an individual's *learning style*. In particular, learning styles are applied cognitive styles, removed one more level from pure processing ability usually referring to learners' preferences on how they process information and not to actual ability, skill or processing tendency (Jonassen and Grabowski, 1993). Although several researchers label cognitive and learning style both as learning style, or use the terms interchangeably, for clarity we prefer to distinguish them and use the term 'style' in cases referring to both.

Following this line of research, different learners approach learning tasks in different ways, or using different styles, and through the interaction with a learning environment they develop sets of behaviour that they are comfortable with (Entwistle, 1981). Such viewpoints have led to suggestions of tailoring educational interactions to learners' cognitive or learning style in the context of computer-based and web-based learning environments (Carver et al., 1999; Bajraktarkvic et al., 2003; Chen and Paul, 2003; Papanikolaou et al., 2003; Triantafillou et al., 2003). The flexibility offered by such environments should enhance learning, allowing learners to develop personal navigation patterns and interaction behaviour that reflects their own cognitive characteristics.

Designing an environment rich enough to accommodate a range of styles is challenging, as the situation is not as straightforward as matching learning materials with style. Modelling style in the context of a learning environment demands from system designers that they build a specific framework describing how to design a variety of options for learners with different approaches to learning (Magoulas et al., 2003). Especially in web-based learning environments, designers also have to deal with the new medium and learning context, and use the innovative tools offered by the Internet to design alternative interactions. However, although several different approaches have been adopted, findings show only a weak link between style and learner preferences (Loo, 2004; Mitchell et al., 2004); or learning style and performance (Harris et al., 2003; Liu and Reed, 1994; Yu and Underwood, 1999); or performance and matching or mismatching to cognitive style instructional methods (McKay, 1999; Pillay, 1998; Ford and Chen, 2000, 2001; Shih and Gamon, 2002). Even if the relationship between style and learner preferences is still an open issue, experimental results suggest that learners nevertheless have preferences about the kind of interaction/presentation of information they receive, although results do not indicate obvious links between specific style categories and preferences for certain designs (Mitchell et al., 2004; Mabbott and Bull, 2004; Papanikolaou et al., 2003). This lack of evidence suggests that there is a need to deepen the study of the relationship between a learner's style characteristics and interaction behaviour. Particularly in a web-based learning environment, researchers need to put more emphasis on learner-demonstrated preferences, where the relationships between learners' selections, navigation patterns, and the nature of the medium, should be carefully examined. To this end, data about system usage during the interaction is especially valuable, since it allows a direct observation of learner behaviour.

In this paper, we argue that while style information can usefully be used to inform the design of learning environments that accommodate learners' individual differences, it is unwise to prescribe an interaction according to an individual's presumed style. We suggest that it is more useful to recommend educational interactions based on the learner's observable behaviour, allowing learners to make the final choice, selecting amongst alternative approaches. The paper is organised as follows. In Section 2 we provide an overview of educational systems that accommodate cognitive or learning style, and present two representative examples of such systems: Flexi-OLM and INSPIRE. In Section 3, experimental results are presented from two empirical studies performed with the systems to investigate how learners' style links to alternative interactions offered by the systems. Based on these results, in Section 4 the issues of learner control over the alternatives proposed, and of modelling learners' interaction behaviour, are discussed. In conclusion, we recommend in Section 5 that, although systems may be usefully designed according to style theory, control should rest with the user.

2. Accommodating a range of styles

Designing adaptive educational systems (Brusilovsky and Peylo, 2003) that accommodate a range of styles builds on hypotheses about the relationship of learning behaviour and style. A valuable resource in this context is research conducted in the area of educational psychology about styles and the way style characteristics influence learner behaviour, preferences and performance. A variety of style categorizations have been proposed which attempt to associate specific characteristics to different categories of learners, and propose instruments and methods for assessing style (Riding and Rayner, 1998; Schmeck, 1988; Jonassen and Grabowski, 1993). In many cases, such categorizations provided the theoretical background for designing the main modules of educational systems and their functionality, and guiding decisions about what the system should offer to learners with different styles in the case of adaptive educational systems (Papanikolaou and Grigoriadou, 2004; Karagiannidis and Sampson, 2004).

In an attempt to organise the different approaches adopted, we identified educational systems that use the style information in order to (i) design the content of instruction—select and sequence educational material, (ii) design tools/representations that support the learners' orientation and navigation in hyperspace, and (iii) design specific functionalities such as the externalisation of the domain or the learner model.

In more detail, educational systems that belong to the first category concentrate on the type and usually the sequencing of material they offer. Adaptation is based on a framework proposed by the authors such as in ACE (Specht and Opperman, 1998), Arthur (Gilbert and Han, 1999), MANIC (Stern and Woolf, 2000) or inspired by specific style categorisations and research studies (Honey and Mumford, 1992; Witkin et al., 1977; Felder and Silverman, 1988) about the type and/or sequencing of instructional material that learners with different styles prefer, such as in INSPIRE (Papanikolaou et al., 2003), CS383 (Carver et al., 1999), *i*Weaver (Wolf, 2002).

Educational systems in the second category concentrate on the 'form' of cognitive activity (i.e. thinking, perceiving, remembering) that learners usually adopt (Triantafillou et al., 2003; Bajraktarevic et al., 2003; Wolf, 2002) aiming to support the learners' orientation and navigation. For example, AES-CS (Triantafillou et al., 2003) adopts the Field dependence/independence (FD/FI) categorisation (Witkin et al., 1977) in order to decide which navigational tools and aids are appropriate to help learners of a particular style to organize the structure of the knowledge domain and move accordingly within. Also, Bajraktarevic et al. (2003) use the Holist/Serialist categorisation proposed by Pask (1976), which is aligned with the Wholist/Analytic dimension (Riding and Cheema, 1991) and with the Global/Sequential categorisation (Felder and Silverman, 1988) in order to provide learners with appropriate linking structures of the content tailored to their style. In *i*Weaver (Wolf, 2002), global learners are recommended to use advance organisers or mind maps, whilst analytical learners are recommended to use sequential lists of key points and components.

The third category includes educational systems that provide learners with multiple representations of specific modules, such as Flexi-OLM (Mabbott and Bull, 2004), which provides learners with multiple representations of their learner model based on Felder and Silverman (1988) style categorisation.

The level of control a learner has over alternatives offered is an important issue. Systems may make such choices for the learner based on their assumed, stated or modelled style (e.g. INSPIRE and AES-CS use specially designed psychological tests to determine learners' style, although they both allow learners to select or change their style during the interaction); or they may allow the learner to select their preferred approach directly.

Flexi-OLM adopts the latter approach. The aim is to promote reflection by learners about their knowledge and learning, by externalising the contents of their learner model to them. Learners may view information about their skill level, knowledge and misconceptions in a choice of seven formats, designed according to Felder and Silverman (1988) style categorisation. Although the design of the views is based on style, the control over which views are used rests with the learner.

Several style categorisations have been used to inform the design of adaptive educational systems, and there are many more that have not yet been considered. What is important in exploiting different style categorizations in educational systems is their potential to support and guide the development of alternatives for learners with different approaches to learning. This research goal has two outcomes for the educational psychology field and adaptive educational systems. Educational psychology may benefit from gathering evidence to evaluate the effectiveness of matching or mismatching instructional methods to learner styles and preferences in e-learning, and adaptive educational systems may improve the effectiveness and efficiency of interaction and adaptation.

Below we present two approaches for designing functionalities of adaptive educational systems based on different dimensions of styles, adopted in Flexi-OLM and INSPIRE. Both systems are designed according to specific learning and cognitive style theory, offering alternatives for learners with different styles, and allowing learners to select the most appropriate approach offered.

2.1. Flexi-OLM: open learner model and learning and cognitive style

An open learner model allows users (usually the learner being modelled) to access the contents of the model. In many cases this is to prompt reflection, and viewing the model is intended to support the learning process. In systems with open learner models there is usually a single method of presenting model information for all users. This may be a skill meter (Weber and Brusilovsky, 2001; Papanikolaou et al., 2003); externalisation of knowledge level in a Bayesian network (Zapata-Rivera and Greer, 2004); descriptive text of knowledge and misconceptions (Bull and Pain, 1995); conceptual graphs with dialogue (Dimitrova, 2003); or other formats. However, few systems offer a choice of view. Flexi-OLM was designed to address this issue. It was designed to accompany an introductory-level university C programming course, with the learner returning for several sessions. The student answers questions to enable the system to model their knowledge, with the model continually updating as the learner interacts further. The learner model is then used to suggest appropriate areas for further study.

Flexi-OLM was designed according to the Felder and Silverman (1988) model of learning style, which consists of four independent dimensions. The sensing/intuitive dimension describes the reception of information, with sensing learners preferring information received externally, through the senses, and intuitive learners preferring information arising indirectly, through intuition. The active/reflective dimension describes the approach to the subsequent processing of this information. Active learners process the information by doing something active with it in the real world; reflective learners prefer to think it over. Although the authors refer to the model as a description of learning style, the visual/verbal and sequential/global dimensions are more consistent with Riding and Cheema's (1991) definition of cognitive style, corresponding to their verbal/imagery and wholist/analytic dimensions. The former describes the extent to which an individual favours information conveyed as images or as text. The latter relates to the method of grasping new material: an organised sequence of steps, or a more holistic approach. Flexi-OLM allows users to view their learner model in seven formats (extended from the four views presented in Mabbott and Bull (2004)): hierarchy of concepts, lecture structure, concept map, pre-requisites, alphabetical index, list ranked according to performance, textual description. This is illustrated in Fig. 1. Coloured nodes indicate how well students understand each topic, ranging from white (poor understanding), through shades of yellow/green (partial understanding), to bright green (full understanding). Topics with misconceptions are indicated by red. Clicking on a topic allows the user to access more detailed textual information about their understanding of the specific concepts, which comprise that topic, including any misconceptions held. Each view holds the same information, but is presented or structured differently.

Flexi-OLM offers four types of presentation more commonly found in isolation in current open learner modelling environments: hierarchical tree (Kay, 1997; Weber and Brusilovsky, 2001), list (Mitrovic and Martin, 2002), map (Dimitrova, 2003; Rueda et al., 2003), and text (Bull and Pain, 1995). This choice is expanded further by offering a second version of some of the formats, in which the information is grouped differently, or presented in a different order. This allows Flexi-OLM to accommodate more of the characteristics identified by Felder and Silverman (1988) as associated with learners with different styles.

The learner characteristics described by Felder and Silverman (1988) provide a basis for the design of views that accommodate three of the style dimensions. The relationship between these styles and the views in Flexi-OLM is shown in Table 1.

In six of the views, the essential information (proficiency on each topic) is conveyed visually (using the colour system), and only in the textual view is it expressed in words. In this sense the textual view is the only truly verbal view, although the other views are not equally visual. The list views, being one-dimensional, require a lower visual ability, while the map views, consisting of multiple connections between concepts, may appeal to the more extreme visualisers. The index and ranked views are aimed at the sensing learner, who focuses on facts, is good at memorising data, is patient with details, and works slowly and carefully, disliking surprises—there is little supplementary information in these views except for the 'facts' (the topic proficiencies). On the other hand, the quick and less careful intuitive learner may not have the patience to examine the model in such a detailed manner, preferring speculation, principles and theories. The pre-requisites view aids with speculation about how understanding of one topic may be related to understanding of another, and the concept map allows the student to focus on conceptual relationships. The map views allow a good overview to be obtained, compensating for the unwillingness to concentrate on details, and also make greater use of symbols (arrows, labels, etc.), something which intuitors are claimed to be highly comfortable with (Felder and Silverman, 1988). The lecture structure view aims to satisfy sequential learners' desire for a logically ordered progression through increasing complexity and difficulty, but may be disliked by the global learner, who prefers to make intuitive leaps, and requires a fuller

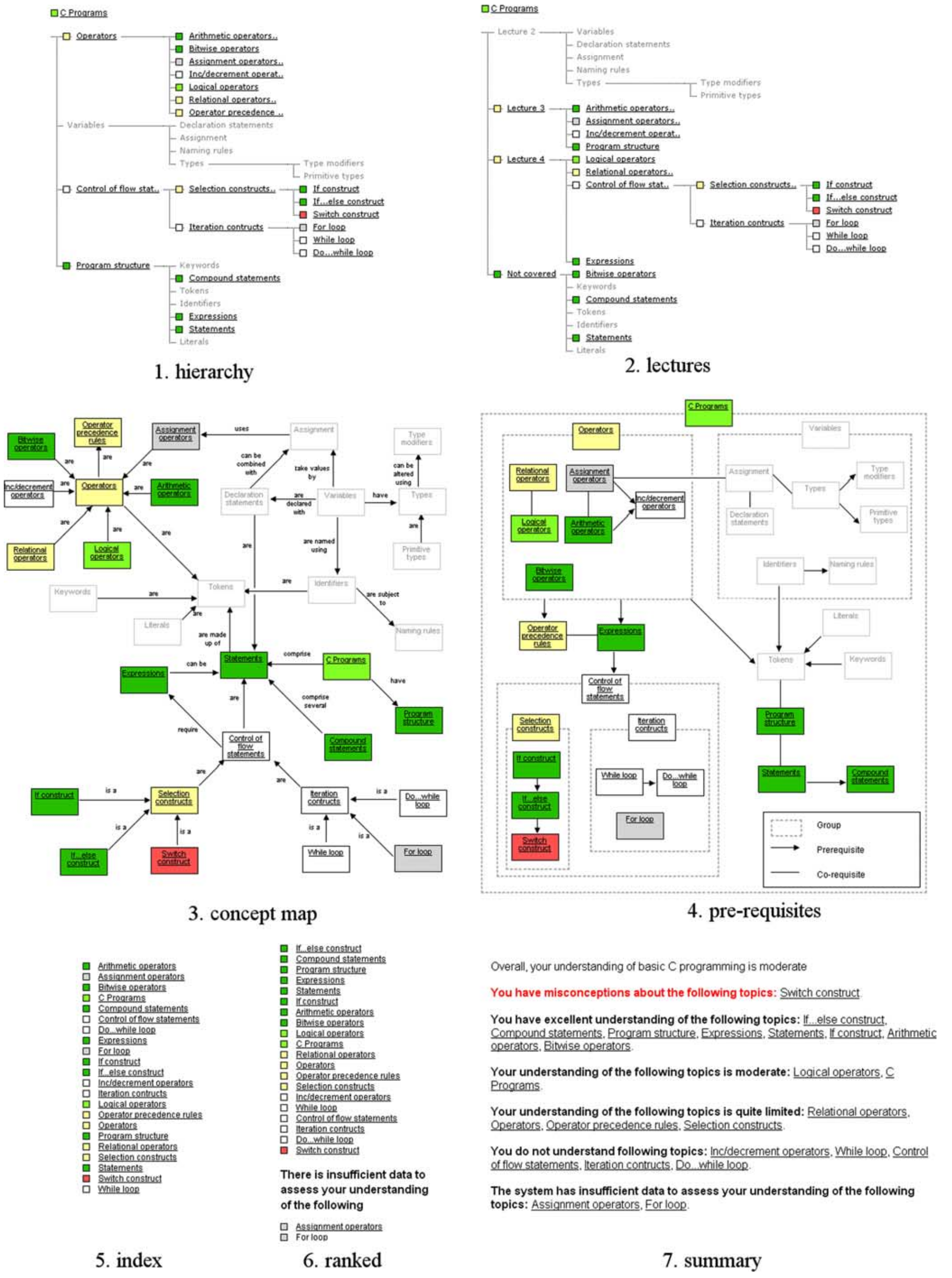

Fig. 1. The seven views of the learner model offered by Flexi-OLM.

Table 1
Relationship between three dimensions of the Felder and Silverman (1988) style model, and the views in Flexi-OLM

Style	View	View	Style
Sequential (steady progression of difficulty, linear reasoning process, can work with partial understanding)	Lecture structure	Hierarchy	Global (makes intuitive leaps; follows non-linear path through material, requires full understanding of how material fits together)
Sensing (likes facts, data; is patient, carefull; dislikes surprises)	Index, ranked	Concept map, pre-requisites	Intuitive (like speculation, principles, theories; dislikes repetition; bored by detail)
Visual (remembers what they see; likes diagrams)	All except textual	Textual	Verbal (prefers words)

understanding of how all the material relates together before attempting to understand the details. These needs are better accommodated by the hierarchy, which allows the globaliser to take a breadth-first approach, and to an extent the concept map. Students who fall in the middle of any of the style dimensions may be more flexible in their use of the views.

The current implementation of Flexi-OLM does not make provision for differences in the active-reflective dimension of learning style. Viewing the learner model may involve a reflective experience, but accommodating active learners could require a higher level of interactivity between student and model, like that found in editable (Kay, 1997) and negotiated (Bull and Pain, 1995) models.

2.2. INSPIRE: adaptive content presentation and learning style

INSPIRE (Papanikolaou et al., 2003) is a web-based Adaptive Educational Hypermedia system designed to support web-based personalised instruction, as well as traditional classroom-based teaching as a supplementary resource. Based on the notion of learning goals that the learner selects, INSPIRE generates a sequence of lessons that correspond to specific learning outcomes, with the aim of supporting the learner in gradually achieving their goal. Moreover, INSPIRE proposes a navigation route through the lesson contents based on a learner's knowledge level and progress, and adapts the presentation of the educational material to the learner's learning style. Honey and Mumford (1992) model was used as the basis for determining the presentation of the educational material.

Based on Kolb's (1984) theory of experiential learning, Honey and Mumford (1992) suggest four types of learner: *Activist*, *Pragmatist*, *Reflector*, *Theorist*. According to Kolb, "learning is the process whereby knowledge is created through the transformation of experience". He suggests that there are four stages, which follow from each other: Concrete Experience is followed by Reflection on that experience, on a personal basis. This may then be followed by the derivation of general rules describing the experience, or the application of known theories to it (Abstract Conceptualisation), and hence to the construction of ways of modifying the next occurrence of the experience (Active Experimentation), leading in turn to the next Concrete Experience. Learners can start anywhere on the cycle because each stage feeds into the next, and the starting point depends on their learning style. This cycle reflects two dimensions (i) how one prefers to perceive the environment or grasp experience, i.e. through concrete or abstract thinking, and (ii) how one prefers to process or transform incoming information, i.e. through active or reflective information processing. By crossing the two dimensions, Kolb differentiated four types of learning style: divergers, assimilators, convergers, and accommodators. Based on the above ideas, Honey and Mumford (1992) built a typology of Learning Styles, identifying individual learning preferences for each stage of the learning cycle.

Honey and Mumford (1992) assessed various learning activities in terms of their relationship to the different learning styles. For example, Activists are considered to prefer activities where there are new experiences, problems, opportunities of active experimentation from which to learn; Reflectors are considered to prefer activities where they are allowed to watch, think, ponder over activities; Theorists are considered to prefer activities where they have the opportunity to explore a model, a concept, a theory; Pragmatists are considered to prefer activities where they can concentrate on practical issues, such as when they are shown techniques for doing things with practical advantages.

In INSPIRE, styles are defined as types of activity reflecting preferences for certain stages of the learning cycle over others. Thus, learners are associated with preferring one or more activity type. Learners are recommended to start from activities that match their style exploiting their own capabilities, and continue with less 'style matched' activities in order to develop new capabilities (Kolb, 1984). For example, the activity-based view of the content provided to Activists suggests that the learner should start with an experimentation activity, e.g. run an experiment following a specified educational scenario that uses a computer simulation. The learner undertakes an active role and through experimentation constructs their own internal representations for the concept they are studying. If the learner needs more help, an example and hints from the theory are available (see Fig. 2—the Activist's view). Also, an exercise is provided offering additional opportunities for practicing. If the learner is a Reflector (see Fig. 2—the Reflector's view), INSPIRE proposes starting by reading an example, continuing with hints from the theory and then trying to complete an exercise. The learner studies all the necessary information before acting. The final activity proposes the learner to use a computer simulation and stimulates them through an educational scenario, to take an active role experimenting with already acquired knowledge.

INSPIRE adopts an instructional framework that integrates theories from the instructional design and the learning style literature (Papanikolaou et al., 2003). The educational material of INSPIRE is organised in pages that are associated with specific outcome concepts of the domain that the learner has to study in order to achieve a learning goal. These pages consist of a variety of knowledge modules that reflect different types of learning activity with varying levels of interactivity such as: theory presentations (definitions, descriptions, conclusions); questions introducing or assessing the concept; examples (concrete instantiations of concepts, application examples, analogies); exercises; activities (experimentation activities, exploration activities, case studies, small projects). Three types of educational material page are developed for each outcome concept corresponding to the three levels of performance (Merrill, 1983): Remember, Use, Find. In these educational material pages different types of knowledge modules are

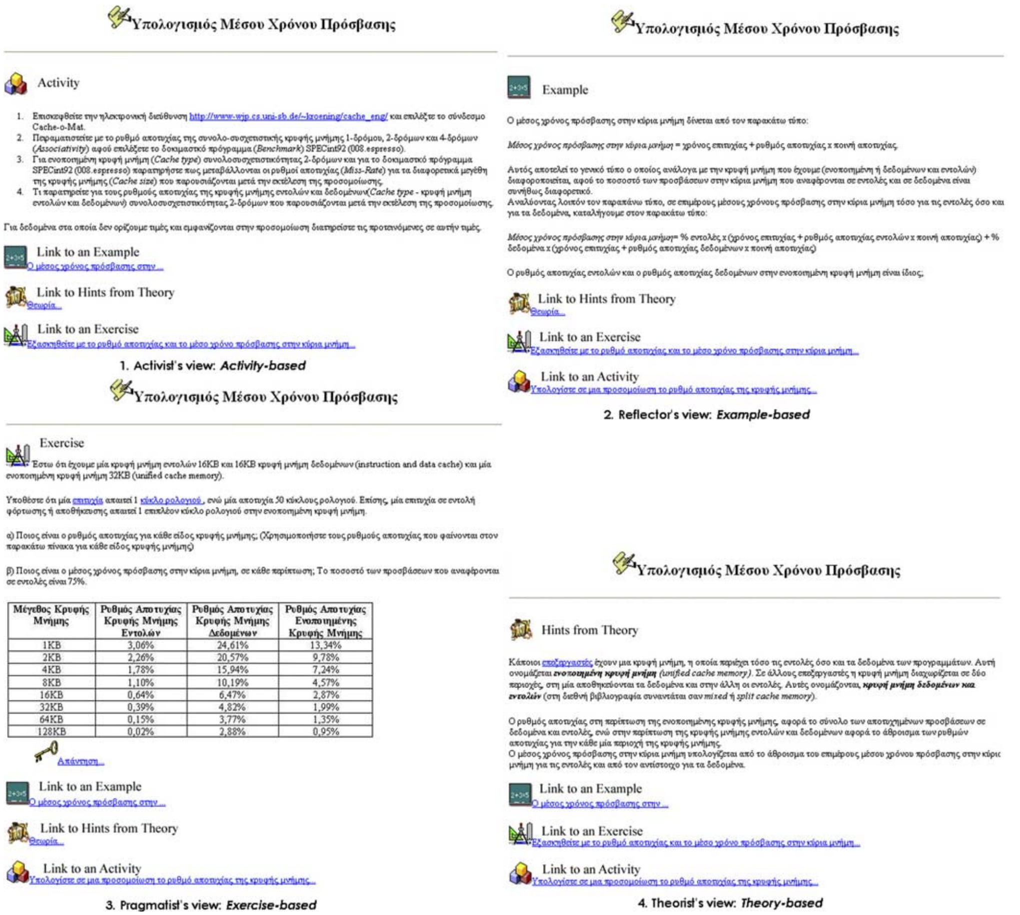

Fig. 2. The four views of educational material pages at the Use level of performance: an educational material page as it appears to the different learning style categories.

included depending on the level of performance to which the pages correspond: (i) pages of the *Remember* level of performance include knowledge modules that introduce the concept and help learners speculate on newly introduced ideas, such as theory presentations of the concept, questions (introductory or self-assessment), and instances of the concept (real examples or analogies of the concept); (ii) pages of the *Use* level include knowledge modules that support learners applying the concept to specific case(s), such as hints from the theory, application examples, exercises, experimentation activities or case studies; (iii) pages of the *Find* level include knowledge modules that aim to encourage learners to find a new generality, principle, procedure, through exploration activities/case studies/small projects.

All learners receive the same knowledge modules. However, the order and mode (embedded or link) of their presentation in a page is adapted based on learning style, resulting in different views of the educational pages (Fig. 2 shows a page of the Use level

Table 2
INSPIRE offers multiple views of the educational material pages that correspond to the Remember and Use levels of performance, in which the order and mode (embedded or appearing as a link) of presentation of the modules differ

Learning style	Educational material pages view	
	Remember	Use
Activists: motivated by experimentation and challenging tasks	*Inquisitory* starts with an introductory question, and continues with links to examples and theory	*Activity-based* starts with an activity, and continues with links to examples, theory hints and exercises
Pragmatists: keen on trying out ideas, theories and techniques	*Expository based on examples* starts with an example, and continues with links to theory and assessment questions	*Exercise-based* starts with an exercise, and continues with links to examples, theory hints and activities
Reflectors: tend to collect and analyse data before taking action	*Expository based on theory* starts with theory, and continues with links to examples and assessment questions	*Example-based* starts with an example, and continues with links to theory hints, exercises and activities
Theorists: prefer to explore and discover concepts	*Inquisitory* starts with an introductory question, and continues with links to theory and examples	*Theory-based* starts with theory hints, and continues with links to examples, exercises and activities

in four views). The relationship between learners' learning styles and the views in INSPIRE is shown in Table 2. For example, the inquisitory view (Remember level) and activity-based view (Use level) of the content, which both focus on knowledge modules with high interactivity, is provided for Activists. It should be emphasised that the different views correspond to study recommendations based on learners' learning style. However, learners have the option to select the knowledge modules they prefer to study, in the order they prefer.

3. Experimental studies investigating learners' style and system use

Although several adaptive educational systems that use style as a source for adaptation have been reported in the literature, just a few empirical studies (usually small scale studies conducted in experimental conditions) have been conducted that illustrate the effectiveness of the adopted approaches. Often empirical studies investigating the usefulness of alternative approaches illustrate the variety of learners' preferences and result in identifying tendencies towards the different approaches proposed, but do not indicate obvious links between specific style categories and preferences for certain designs (Loo, 2004; Mitchell et al., 2004; Liu and Reed, 1994; Yu and Underwood, 1999; McKay, 1999; Pillay, 1998).

In this Section, we present two experimental studies conducted to investigate links between specific style categories and learning preferences during learners' interaction with Flexi-OLM and INSPIRE. The aim was to *explore* relationships between style, learners' preferences and interactions with the system. In particular, we investigated:

(a) whether learners of the same style category have similar preferences regarding the alternatives offered by the system; and (b) whether learners' selections during the interaction match their style.

The *goal of the studies* was to provide us with (i) direct information from the systems' intended users about their learning preferences and their opinions about the alternative approaches offered; (ii) real data about the way learners of a particular learning or cognitive style use the systems.

The selection of the *educational systems* involved in the experimental studies (Flexi-OLM and INSPIRE) was based on the following criteria: (a) system design should be based on a theoretical background from the area of learning and/or cognitive style; (b) the systems should offer alternatives for learners with different styles, but allow learners to select which to follow; (c) there should be a variety of system functionalities designed to accommodate style differences. Thus Flexi-OLM and INSPIRE were considered appropriate for this study as they use different style categorisations to model learners' preferences, and offer alternatives which learners are able to control. Moreover, in these systems styles have been used to design different functionalities, which are crucial for adaptive educational systems, such as the externalisation of the learner model (Flexi-OLM) and the presentation of the educational content (INSPIRE).

Data analysis was based on questionnaires and log files. The *experimenters* were researchers of the team working for the design and development of the educational systems. At the beginning of each study, they introduced the system to the participants. During the study, the role of the experimenters was limited to answering questions on the subject matter and the learning tasks (exercises, activities) that the participants should perform and submit. The *test users* covered a main category of the system's intended users based on their level of education (university level: undergraduates or postgraduates) and the content of their studies, as they had to work on learning tasks of a particular domain during their interaction with the system. Learners during both studies followed a *usage scenario* to ensure that they would experience the alternatives offered by the systems to different styles, and be able to rate them in terms of some authentic learning need.

3.1. Study 1: Flexi-OLM

The first study was undertaken in the 2004–2005 academic year, to investigate whether there is a link between style and preferred view of the learner model in Flexi-OLM. Thirty-six students participated from two groups. 8 were third year undergraduates on a 3 year BEng/4 year MEng degree in Computer Interactive Systems, in the Department of Electronic, Electrical and Computer Engineering at the University of Birmingham, and 28 were on a 1-year MSc course in the same department, studying for a variety of degrees spanning the electronic, electrical and computer engineering field. Both groups are required to study C programming (the domain of the study) as part of their degree. Students worked independently, one at each computer. The participants followed a specific usage scenario: at first they were asked to choose a topic they were confident in and answer the system's questions on this topic. They then followed a cycle of (a) interacting with the learner model created from their responses in order to select the next topic to answer questions on, and (b) answering questions on their chosen topic.

Questions were presented singly, with the user able to switch topics or view the learner model at any time. Some questions were presented in a multiple-choice format, and some required short numerical answers corresponding to the values of variables or the output of a sample program. With the aim of observing students using their open learner model in a realistic setting, we avoided constraining their interaction as may have occurred if using specific tasks regarding interpretation of the model, as this may have biased usage in favour of a particular view. For example, a student asked to determine which topics they have the strongest understanding of, may favour the ranked list, where better known topics appear at the top of the list, and less well understood topics at the bottom. Thus, although the primary use for the model was choosing which topic to study next, students were not advised on how to interpret the different views of the learner model, or guided on whether they should consolidate existing knowledge or tackle new areas, progress through the curriculum or focus on related concepts, etc. This enabled us not only to more easily identify which views were preferred by learners in order to compare this information to their style as measured by Soloman and Felder (1999) Index of Learning Styles, but also to design future studies that could take uninfluenced preferences as a starting point. (For example, future work will consider the extent to which each of these, and other views, is most suited for use in conjunction with a variety of tasks, and, therefore, the extent to which users may be supported in their selection of views with reference to both to their individual preferences and the utility of the views in relation to the task.)

After using Flexi-OLM for around 40 min, students rated the usefulness of the views in the context of the task of selecting topic areas by signalling their agreement (on a five-point scale: strongly agree–strongly disagree, see Table 3). Separate ratings were sought for each view (rather than a list ranking the views in order of utility), so that students could express equal preference for a group of views if necessary. The final statement provides an indication of the perceived utility of having more than one view available, and also how comfortable students felt in selecting a view from the choice available. Interaction with the system was logged in order to observe how often each view was visited by a particular user. Changes in understanding were not considered an appropriate indication of the effectiveness of the views—the current implementation of Flexi-OLM is not a full tutoring system (it was designed to be used alongside standard course notes rather than to provide tutoring) and, in such a short timescale, the students did not have the opportunity to consult course notes to revise topics they may have identified as weak.

Each learner's questionnaire responses were converted to a score from 1 to 5 for each view, allowing their preferences for the views to be ranked. The Index of Learning Styles questionnaire (Soloman and Felder, 1999) was used to assess the style of each participant according to the four dimensions of the Felder and Silverman (1988) model described above. Fig. 3 presents a comparison of stated preferred views and individual style. The

Table 3
Statements in the post-usage questionnaire for Flexi-OLM

Statement	Options
1–7, The <*view-name*> view was useful	Strongly agree ☐ ☐ ☐ ☐ ☐ strongly disagree
8, Having multiple views available was useful	Strongly agree ☐ ☐ ☐ ☐ ☐ strongly disagree

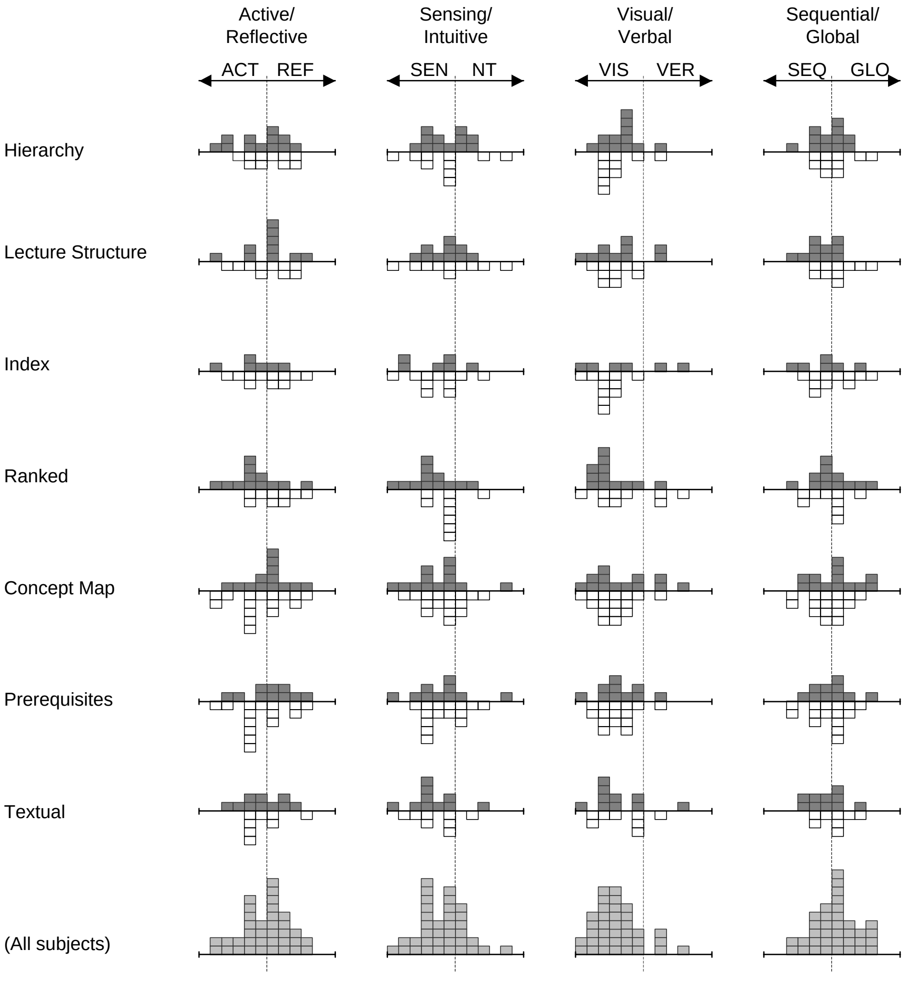

Fig. 3. Style results compared to preferred learner model views in Flexi-OLM.

bottom row in Fig. 3 shows the style distributions in each of the four dimensions for the full set of 36 participants. Each square represents a single participant, with squares closer to the ends of the axis indicating participants with more extreme styles. Each of the other seven rows presents a pair of distributions for two particular subsets of the 36 participants. For each row (view), the grey distribution above the axis corresponds to the styles of the subset who have given that view their highest, or equal highest rating. The white distribution below the axis represents all those who have given that view their lowest, or equal lowest rating. For example, 12 students gave their highest rating to the hierarchy view, 10 gave it their lowest rating, and the remaining 14 ranked it neither best nor worst. Each of the 12 students thus corresponds to a specific square in each of the four grey distributions on the top row, the group of 10 students are represented by the four white distributions in this row, and the other 14 do not feature here.

Table 4
Number of users according to amount of interaction with each view

View	Less than 3 interactions	3–10 interactions	More than 10 interactions
Hierarchy	8	10	18
Lecture structure	9	9	18
Index	7	9	20
Ranked	8	12	16
Concept map	12	13	11
Pre-requisites	4	10	22
Textual	9	11	16

Fig. 3 suggests that no single view represents the best way of presenting the model as each has several people who consider it the most useful, and several who consider it the least useful. This finding is reinforced by analysis of the system log files, which show that each view had people who made extensive use of it and also people who made very little use of it, as illustrated in Table 4. This indicates how often users interacted with each view, where an interaction involves either opening a particular learner model view, or exploring a concept within that view.

In the questionnaires (see Table 3), only 3 students rated all views equally. Fig. 3 provides no evidence of a strong link between preferred view and any aspect of style, since the individual distributions in each dimension are roughly the same shape as the overall distribution in that dimension. Most views appear to be both liked and disliked by people with all styles. To illustrate this point further, Fig. 4 shows the scores given to the textual and concept map views by participants according to their position on the visual/verbal scale. Despite the fact that the textual view is a sentential presentation, the two most visual learners still found it useful and awarded 4 out 5, while the lowest score (1 out of 5) came from one of the verbal learners. Similarly, the concept map appears to draw high and low ratings in equal measure across the spectrum, despite expectations that it might suit the most visual learners better.

Combining the four dimensions together provides a possible 16 (2^4) broad style categories, one example of which would be all the users who are reflective, intuitive, visual, and global. The individual preferences of the six students with the reflective-intuitive-visual-global style are shown in Table 5. Most of the seven views are listed as

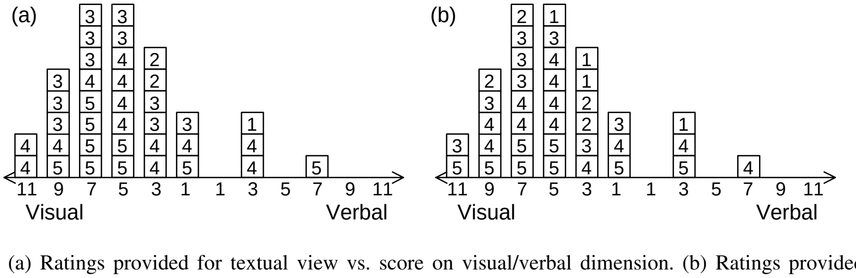

Fig. 4. (a) Ratings provided for textual view vs. score on visual/verbal dimension. (b) Ratings provided for Concept Map view vs. score on visual/verbal dimension.

Table 5
Preferred views of the learners in the reflective-intuitive-visual-global group

User	Favourite view(s)	Least favoured view(s)
7	Hierarchy	Lecture structure
17	Lecture structure	Concept map, prerequisites
18	Hierarchy, prerequisites	Index
25	Concept map	Lecture structure
28	Concept map, prerequisites	Hierarchy, lecture structure
32	Textual	(Rated all others equally)

both favourite and least favoured, providing an illustration of the clear differences in preference between users of similar styles.

Of course it could be argued that a poor mapping from style theory to specific representations could explain why the expected connections between style and preference were not demonstrated in the results, even if they were present. However, assuming the range of presentations is sufficiently broad to trigger *some* difference in reaction from users of different styles, this would be more likely to lead to unexpected relationships being shown rather than the relative lack of connection that occurred. In general, students found it useful to have multiple views available (see Bull et al., 2005) and had no difficulty in selecting one or more views to use in the inspection of their learner model. Thus, we recommend that a variety of views on the model are available for learners, but that even when the views are designed based on style theory, the choice of view to present to a learner not be prescribed based on their style.

3.2. Study 2: INSPIRE

Two experiments were undertaken with INSPIRE in the academic years 2003–2004 and 2004–2005, comparing data on study preferences and learning style. Forty-eight students participated from two groups: 23 were undergraduates in Informatics and Telecommunications at the University of Athens (first study), and 25 were on a 2-year MSc course in the same department (second study). In both studies, participants worked independently, one on each computer, and studied two outcome concepts of a learning goal from the domain of Computer Architecture (first study) and Computer Programming (second study). Students worked with INSPIRE for 2 h, while the complete study lasted about 3 h. All the steps that the participants had to follow were listed in a usage scenario. Several questions were embedded in the different phases of the usage scenario, reflecting likes and dislikes, problems identified, suggestions, etc. The scenario had three phases: (a) Phase 1, the students worked as designers in a realistic context, and were asked to design educational content using multiple types of material. Through this activity students are prompted to make their own proposal without being influenced by the design approach of INSPIRE; (b) Phase 2, students worked with the system and performed specific learning activities. Students were asked to study the educational material pages (corresponding to the Remember and Use levels of performance) of two outcome concepts. They were also asked to answer the questions, exercises, activities included in these pages using the notepad of each page. They were free to study the pages and the knowledge modules in the order they

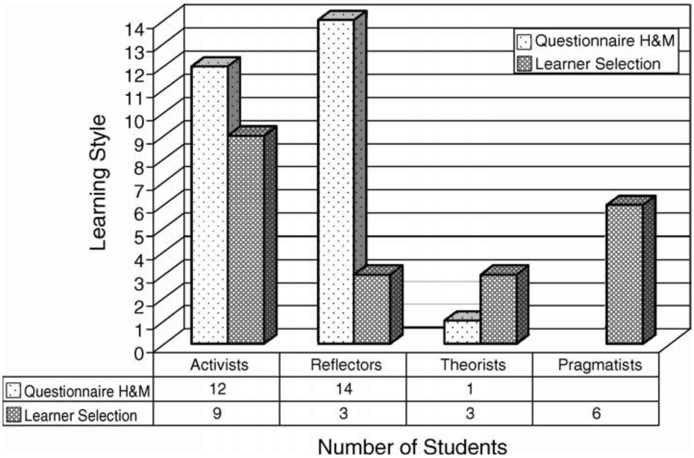

Fig. 5. Distribution of students for each learning style, distinguishing those whose learning style was identified through the submission of the questionnaire proposed by Honey and Mumford (1992), and those who selected their learning style themselves.

preferred. At the end of their study they were asked to change their learning style category in order to check the alterative views of the educational material pages for the Remember and Use levels of performance. This was to ensure that students would experience the alternatives offered in order to be able to evaluate them; (c) Phase 3, students were asked to compare their initial designs (Phase 1) with those offered by the system, reflect on their preferences, and suggest the most appropriate approaches matching their way of studying.

The first time participants logged on to INSPIRE, they had the options (a) to submit the Honey and Mumford (1992) questionnaire in order to allow the system to automatically identify their learning style, or (b) select their dominant learning style manually, based on information that the system provided about the general characteristics and learning preferences of each category, as described by Honey and Mumford (1992). Most students were Activists and Reflectors (see Fig. 5). This may be because they all study Informatics and so, potentially, are representative of a specific group with similar learning preferences.

Phase 1. At the start of the study, and before students logged on to INSPIRE, they filled in an introductory questionnaire. They were asked to *suggest* which strategies they would adopt in studying the various concepts of the domain using educational material of multiple types such as theory presentations of the underlying concepts, questions (introductory and self-assessment), real-life examples or analogies of the concepts, application examples, solved exercises, cases studies, experimentation and exploration activities. In more detail, they were asked (a) to enrich the proposed types of educational material with three more (see Table 6—Phase 1, *Question* 1), (b) to propose combinations of the different types of material (the above and those proposed by themselves) that they would select to study and the sequencing they would follow, if they needed to achieve the three levels of performance for each concept of the domain: Remember, Use and Find

Table 6
A sample of the questions posed to students during the three phases of the usage

Phase 1: Learners work as content designers
Suppose that you attend a web-based course delivered through an Adaptive Educational Hypermedia System. The content of the course includes theory presentations of the underlying concepts, questions (introductory and self-assessment), real-life examples or analogies of the concepts, application examples, solved exercises, case studies, experimentation and exploration activities.
Question 1: Propose three more types of material (provide brief descriptions) to be included in the course.
Question 2: Propose a sequencing of the above educational material types (including the ones provided by the course and those you proposed) that you *would* follow in order to achieve each of the three levels of performance: Remember, Use, Find. Justify your answer.

Phase 2: Learners interact with INSPIRE and perform specific learning activities
The knowledge modules comprising an educational material page of the *Remember level of performance* are (a) a question that introduces the concept or self-assesses a learner's knowledge of the concept; (b) theory presentations of the concept; (c) real examples or analogies of the concept.
Question 1: Which sequencing of the above modules did you follow when studying such pages ?
☐ The sequence suggested by the system
☐ Other (propose a specific sequencing matching your way of studying)
Question 2: Evaluate the usefulness of the different modules. Which do you think helped you best *understand* the concept? Justify your answer.
The knowledge modules comprising an educational material page of the *Use level of performance* are (a) hints from the theory of the concept; (b) an application example; (c) an exercise; (d) an activity.
Question 3: Which sequencing of the above modules did you follow when studying such pages?
☐ The sequence suggested by the system
☐ Other (propose a specific sequencing matching your way of studying)
Question 4: Evaluate the usefulness of the different modules. Which do you think helped you best *apply* the concept? Justify your answer
Question 5: Select the learning style that matches your way of studying (try the different styles and check the views proposed for each one for both the Remember and Use levels of performance)

Phase 3: Learners reflect on their way of studying
Compare your proposal at Phase 1 with your selections during your interaction with INSPIRE at Phase 2. In particular, compare the contents of the pages you designed for the three levels of performance at Phase 1 with the view you selected as matching your style at Phase 2
Question 1: Justify the similarities/differences you identify
Question 2: Reflect on your initial proposal and the alternative views of INSPIRE and propose the contents of the pages (knowledge modules included and sequencing) that you think most appropriate at each level of performance. Justify your answer

(brief descriptions of these levels were also provided), and to justify their selections (see Table 6—Phase 1, *Question* 2).

The specific questions prompt students to reflect on their way of studying in a realistic context with the aim of speculating on the design of educational material. The aim is also to prepare students for the next phase and support them in understanding the alternative views provided by INSPIRE for learners with different styles.

Results show a range of preferences in the way students decided to combine and study the educational resources for the three levels of performance. Although many combinations were proposed, we observed similarities in students' preferences and grouped them according to the general strategies underlying their selections as presented in their justifications. Thus, we distinguished three strategies for the Remember level (Theory-based, Example-based, Inquisitory) and four for the Use level (Theory-based,

Table 7
Study strategies of students with specific learning styles for the Remember and Use levels of performance

Study strategies at the *Use level* → / Study strategies at the *Remember level* ↓	*Theory-based*: focus on theoretical presentations of how the concept applies in different cases	*Example-based*: focus on application examples accompanied by solved exercises	*Exercise-based*: focus on exercises that students should solve	*Activity-based*: focus on activities through which students discover the concept
Theory-based: starting from theory and continuing with examples and questions		1A 2R		
Example-based: starting from examples and continuing with case studies or theory and assessment questions		4A 3R 3A 1R 1T	2R 1A 1P	1R 1A
Inquisitory: starting from introductory questions and continuing with theory or examples	1R -	4A 4R 1T 4A 1R 1T 4P	1A 1R IT IP	2A IR

Where *i,* number of students; A, Activists; R, Reflectors; P, Pragmatists; T, Theorists. Each cell is split into two rows: the upper row refers to those students who submitted the Honey and Mumford questionnaire; the lower row refers to the students who selected their learning style themselves.

Example-based, Exercise-based, Activity-based) which are presented in Table 7. At the Find level of performance almost all students chose to concentrate on activities and case studies. As depicted in Table 7, no clear link was identified between students' learning style and study strategies, or between the two groups of students, i.e. those who submitted the Honey and Mumford questionnaire and those selected their learning style themselves. However, both Activists and Reflectors showed a tendency towards the combinations of Example-based (Remember level)/Example-based (Use level) and Inquisitory/Example-based strategies: 7 out of 21 Activists and 4 out of 16 Reflectors seem to prefer the first approach, while 8 of the 21 Activists and 5 of the 16 Reflectors preferred the second.

Phase 2. Students worked with INSPIRE for about 2 h, studying the proposed educational material pages of the Remember and Use levels for two outcome concepts, and submitted the proposed introductory or self-assessment questions, exercises and activities. During their interaction they had to answer questions about the order in which they studied the proposed knowledge modules and their usefulness. Several questions were posed to students which prompted them to evaluate the educational material and the modules they had already studied in terms of their subjective estimation of the degree of support offered in achieving specific levels of performance (see Table 6—Phase 2, *Questions* 1, 2, 3, 4). Most students answered that they studied the modules in the proposed order, even though they had proposed a different order in the introductory questionnaire (Phase 1). Analysing students' comments on the usefulness of the various knowledge modules, we also detected different study preferences amongst the students. Some of the participants liked the Inquisitory view (starts with an introductory question leading students to speculate on newly introduced ideas), while others found little use for the questions introducing the concepts in the Inquisitory view (instead they preferred the expository view of the theory which starts with a concept presentation and ends with self-assessment questions). Also, some students found experimenting with activities very interesting and motivating as "this way we have the opportunity to discover the underlying concepts by experimentation"; others reported that the examples helped them understand, and apply the different concepts. However, despite their initial selections (as presented in Phase1), only a few students from both groups chose to change their style at the end of this phase (5 out of 21 Activists, 5 out of 17 Reflectors, 1 out of 4 Theorists, none of the 6 Pragmatists). Note that at Phase 1 only 2 Activists selected the Activist's views of INSPIRE (see Table 2, Inquisitory/Activity-based views), 2 Reflectors the Reflector's views (Theory-based/Example-based), 1 Pragmatist the Pragmatist's views (Example-based/Exercise-based) and none of the Theorists the Theorist's views (Inquisitory/Theory-based).

We also investigated the students' log files that record participants' interaction with INSPIRE, in order to explore relationships between learning style, study preferences and interactions with the system. In the log files we observed that different routes were used across educational material pages, knowledge modules and students. It was clear that there are students of the same learning style category who select and use educational resources following the system's suggestions, but there are also others who follow alternative approaches during the interaction. Below, through a qualitative analysis describing navigation patterns of a few participants of the same style, we aim to provide meaningful observations of students' navigation patterns. For example, navigation patterns observed included a student visiting all modules of a page following the order proposed by the

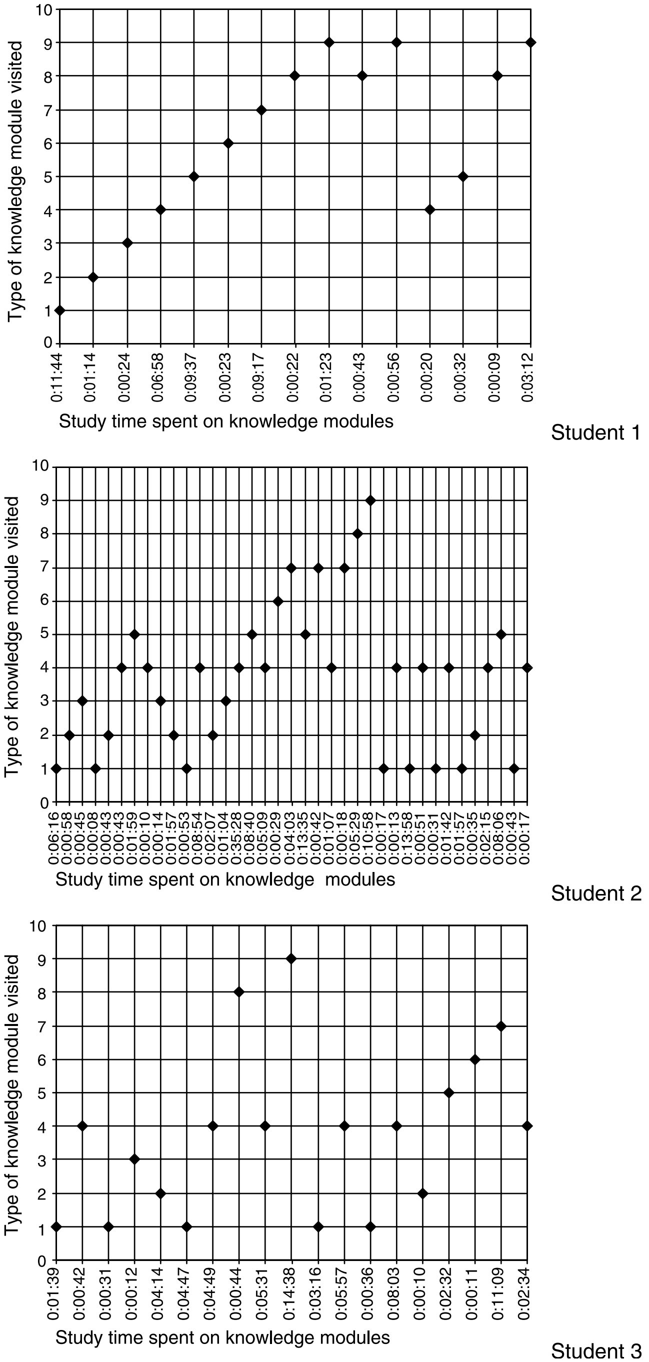

Fig. 6. A sample of the navigation patterns of three Activists (Student 1, Student 2, Student 3) during study of the

system and then either re-visiting the same knowledge modules in the same order (see Fig. 6—Student 1: 1,2,3,4,5,6,7, 8,9, 8,9, 4,5, 8,9), or re-visiting specific types of knowledge modules (see Fig. 6—Student 2: 1,2,3, 1, 2, 4, 5, 4, 3, 2, 1,2,3, 4,5, 4, 6, 7, 5, 7, 4, 7, 8, 9, 1,4, 1,4, 1,4, 1, 2, 4,5, 1,4, usually revisits questions (1), activities (4), examples (2,5)). Although the data is limited as students worked with only two outcome concepts, the differences observed in their navigation patterns cannot be easily linked to their learning style or performance.

Moreover, taking a student's time spent studying and the number of visits for each type of educational material as indicators of their study preferences, we observe that Student 3 worked mostly with the questions, activities and exercises, and less with theory or examples (navigation pattern: 1,4,1,3,2,1,4,8,4,9,1,4,1,4,2,5,6,7,4, Study time on Theory = 0:23—number of visits on theory modules = 2, Examples = 6:56—visits = 3, Activities = 27:36—visits = 6, Exercises = 11:09—visit = 1, Questions = 10:49—visits = 5). Student 2 seems to have worked more with the examples while trying to deal with the activity (number of visits on Examples = 9 and study time = 38:40, whilst number of visits on Theory = 4 and study time = 2:32). The above data seems to confirm the hypothesis that students differ in the way they select and study educational resources, but with no obvious link between preferred view and learning style. The particular sample and domain (students studying Informatics) may influence the results, as most are Activists and Reflectors. Nevertheless, following the theory of learning style, people having a common background are expected to have similar learning preferences. In our case this was not confirmed as different preferences were observed amongst people with the same style.

The task of interpreting navigation patterns is a very complicated and ambiguous task and in no case unique. For example, Student 1 followed a linear approach, visiting all the modules provided in the order proposed by the system, but the time spent on several of the modules is quite limited. In order for this pattern to provide meaningful information about students' preferences, it should be combined with information about the state of the learner (e.g. knowledge level, learning style), the resources visited (e.g. type of module, semantic density of module reflecting the study time proposed by the instructor or mean study time spent by peers), the context that affected the student's selections (e.g. navigation support provided by the system, content sequencing: the order in which the modules appear to the student, tools offered) (Papanikolaou and Grigoriadou, 2005). Thus, in the case of a student being successful in accomplishing the tasks, the navigation pattern of Student may indicate that the student is an expert on the domain (so the time spent on the resources is sufficient for an expert) and Activist (as the sequencing followed matches the order an Activist is expected to follow). However, in the case of failure it may indicate that the student should spend more time on the resources or change study strategy. Of course in

outcome concept 'Loop construct'. The diagrams illustrate the types of educational material that the students visited and the time they spent studying each of them. The *y*-axis shows the different types of module included in (a) the pages at the Remember level of performance: (1, Question; 2, Example; 3, Theory), (b) the pages at the Use level of performance: (4, Activity; 5, Example—application; 6, Theory Hints; 7, Exercise) (c) the 'Recapitulation' page including a summary, which reviews the content presented for the particular concept: (8, Recap), the 'Assessment test' page: (9, Eval). The order of the modules reflects the order in which they appear to Activists.

order to reach a safe conclusion, the students, contribution is also of major importance as they know better what they were doing and why. Thus, an extensive investigation of students' navigation patterns in which students should also participate in characterising their interaction with the system, could provide valuable data for the interpretation of students' interaction behaviour and further support the design of system recommendations. A first step towards this is to design the externalisation of data about learners' interaction behaviour, illustrating the way they select and use resources and system functionalities/tools, with the aim of enhancing their awareness of their style characteristics. This is the next step of this work. In Section 4, these issues are discussed further.

Phase 3. In the final stage students were asked to reflect on their initial proposals (Phase 1) and compare them with the approach they adopted while working with INSPIRE (Phase 2), in order to end in those strategies that better match their study preferences for the three levels of performance (see Table 6—Phase 3, *Questions* 1,2). Through the questions distributed throughout the three phases of the usage scenario, we aimed to gradually encourage learners to reflect on their study preferences, work with the alternatives proposed by INSPIRE for the different styles, and then decide on the approach that best matches their perceived way of learning. Most students agreed with the approach they followed in INSPIRE. Interestingly, even in cases where students remained with their initial proposals (Phase 1), which were different from INSPIRE's approach for the specific learning style, they characterised INSPIRE's approach as useful and matching their preferences. The reason for this may be (as one of the students reported) that those students had selected almost the same modules as INSPIRE for the different levels of performance. This gave them the sense of using the same approach as INSPIRE even if they had selected a different ordering of the modules. Thus analysing the students' answers, 7 out of 47 students remained with their initial strategy which differed from INSPIRE's approach, 12 of the 47 students changed their initial approach to the one proposed by INSPIRE, 11 out of 47 changed their initial approach to a new one influenced by INSPIRE, and 17 adopted a similar approach to INSPIRE. These results seem to be encouraging for the design of INSPIRE, but combined with the results of Phase 2 where students' perceptions of their study preferences seemed to differ from their actual selections, they also raise several questions that need to be further investigated, such as: 'How do system suggestions influence students' selections?' or 'Should we trust self-report data to characterise learners' activity, or their actual selections during the interaction?' 'How aware are students of their study preferences in order to be able to identify a style in advance, which would match their preferences in practice?' or 'How could the system enhance students' style awareness during interaction?'. In the following section we further discuss several of the above issues.

4. Discussion: modelling learners' interaction behaviour

Designing interactive personalised learning environments could benefit from taking individual differences in approaches to learning into account. Systems should be designed in the knowledge that students have different preferences. What we know about learning and cognitive style (even if the way it applies is still an open issue) is a good basis for choices offered in a system—as in the examples presented in this paper. However, experimental data suggest a variety of learner preferences and tendencies with reference to the approaches offered, which are not easily predicted based on style (see Section 3). Thus, although style information can be used to inform the design of educational systems that accommodate individual differences, it would be wise to recommend interactions based on learners' *behaviour*. Systems should allow learners or learners' interaction behaviour to select or trigger the appropriate approach in the specific context. Information describing learners' behaviour could also be externalised to learners with the aim of enhancing reflection and style awareness. Below, we discuss various approaches towards these directions.

A quite simple approach, apart from using the results of a style identification questionnaire (or similar), might be for learners to self-diagnose their preferred approaches to learning according to given style descriptions, and advise the system of the most appropriate learning methods accordingly. This has the advantage that learners would not have to answer a series of questions, some of which may not appear to the student to be of relevance to their educational interaction (e.g. Soloman and Felder (1999) "When at a party I am more likely to remember—what they said about themselves/what they looked like"; Riding (1991) "Fire engine and strawberry are the same colour—true/false"). For example, ACE (Specht and Opperman, 1998) uses interviews in order to help learners decide on specific aspects of their learning style preferences. In INSPIRE learners may identify their style by submitting the questionnaire proposed by Honey and Mumford (1992) which consists of 80 questions, but they also have the option of selecting their style themselves, based on information that the system provides about the characteristics of each category. However, a disadvantage may be that some students could find it difficult to identify their style through such descriptions; or that their perceived learning style may not be the approach that they would actually use in a specific system in practice. Although we have seen from INSPIRE and Flexi-OLM that students are able to select presentations or different approaches to an interaction for themselves, we have not shown that they are able to relate this to their perceived ways of learning. It may be difficult for learners to themselves identify a style in advance, which would match their preferences during their interaction with a system, even when this system has been designed for differential use by learners with different approaches to learning (see Section 3.2 experimental data comparing students' self-report data with their actual selections in INSPIRE).

Another interesting approach would be to design aspects of systems around the idea of stereotypes (Rich, 1983) as in standard stereotypical approaches to user modelling, where a stereotype defines a set of characteristics or attributes that are inherited by a user assigned to that stereotype. Although stereotypes would be based on learning or cognitive style, we would allow learner behaviour within the adaptive system to trigger the stereotype, rather than assigning a stereotype according to the results of an evaluation of the learner's style. An example would be a system that observes learner behaviour and activity in the environment, and then makes recommendations about the presentation of information or interaction type according to the levels of success experienced by the learner, with each of the interaction methods. Such recommendations need not necessarily be matched with the individual's style. (See Bull (2004) for an example based on Kolb (1984) learning cycle.)

Another promising approach would be to use learners' interaction protocols to model their behaviour. Interaction protocols refer to the series of events that occur during system usage with corresponding time stamps (Rouet and Passerault, 1999). This type of information could be used to guide system decisions about what to recommend during an interaction as well as to prompt learners to reflect on their learning. Learners' observable behaviour during an interaction could be further exploited to provide a view of learners' cognitive activity as it unfolds, and their preferences and progress in a particular context. Analysing learner-system interaction protocols is a valuable approach in this direction, as it allows a direct observation of learner strategies (Rouet and Passerault, 1999). However, interaction protocols are sometimes very complex, including sets of heterogeneous data that must be carefully handled in order to yield meaningful information. Moreover, as learning tasks involve complex interactions, in order for the system to make useful recommendations, relevant methods should be defined to characterise interaction with specific resources and system functionalities in a particular context, and link them with preferences and performance (Papanikolaou and Grigoriadou, 2005). This process demands a combination of qualitative analysis of learners' navigation patterns, with quantitative indicators such as number of hits on resources, frequency of re-visits on specific resources, etc. In this process, key issues are the selection of the appropriate data, their analysis and interpretation as also discussed in Section 3.2.

In most studies that explore ways to characterise learners' navigational paths in terms of learning preferences and style (e.g. Andris, 1996; Ford and Chen, 2000; Reed et al., 2000; Lu et al., 2003; Papanikolaou et al., 2003; Calcaterra et al., 2005), learners' navigational behaviour is analysed in order to evaluate the impact of style in learners' performance and/or preferences of specific designs during the interaction. But what if we present learners with an analysis of their interaction with the learning environment—how could such information support learners in self-diagnosing their preferred approaches to learning, and selecting among alternatives offered? This information needs to encourage learners to reflect on their learning process and think about why they are doing what they are doing, and even to gather evidence to evaluate the efficacy of their moves (Barab and Duffy, 2000). Open learner modelling (Bull and Kay, 2005) offers a useful way to achieve this, as suggested by the example of student-system interaction about learning strategies employed by the student during an interaction (Bull, 1997).

5. Conclusions

The design of web-based learning environments should incorporate alternative approaches to learning and instruction, as learning is a complex process and the variety of learners in the e-learning context is great. Valuable resources in this process are theories from the fields of instructional design, didactics, cognitive science, and individual differences including aptitudes, skills and preferences. We recommend that system designers explore such theories and use them as the theoretical basis to develop alternative options for various functionalities of their systems, through which learners may select the most appropriate, according to their learning needs. Learners having the opportunity to view and interact with alternative approaches that may match or mismatch their preferences have a good opportunity to reflect on their learning, and develop metacognitive skills such as awareness of their learning style and study preferences. However, operationalising the prescriptions that such theories provide is not usually a trivial task. Additionally, theories that have proven their effectiveness in classroom-based settings need to be reconsidered in order to provide the basis for the design of instruction in the e-learning context.

Styles relate to learners' mental abilities (Jonassen and Grabowski, 1993) and thus could be a valuable resource in designing learning environments that provide individualised support to learners and promote reflection in learners about their knowledge and learning. The challenge is how to exploit this line of research to inform the design of web-based learning environments. There is no unique approach. The two design approaches that have been implemented in Flexi-OLM and INSPIRE were presented in Section 2 as an illustration. In both systems specific style categories have been used to design different functionalities such as the externalisation of the learner model, or the adaptive presentation of content. Designers should take into account that learners usually do not belong only to one style category and that learning style in particular can be modifiable either at will or by a change of circumstances (Honey and Mumford, 1992). Thus, the core of learning environments that accommodate individual differences should be the provision of many alternatives designed based on different dimensions of style. Nevertheless, we would advocate learner choice in the selection of alternatives that best match their preferences, while providing system recommendations based on their success and/or interaction behaviour. Various reasons lead to these suggestions: (a) the way style information is used to inform a system's design is an open issue and even if this design has been inspired from a theoretical background, it still reflects the designer's perspective. The experimental data of Section 3 showed that students differ in the way they select and study educational resources, whilst expected connections between style and preference were not demonstrated in the results. Thus, it would be wise, during the interaction, for the system to recommend educational interactions based on the learner's observable behaviour rather than their learning or cognitive style. Although the sample in both experiments was unbalanced (for example in Section 3.1 the data includes only four verbalisers and in Section 3.2 most students are activists and reflectors), the experimental data still provides evidence to support our argument that interactions should not be prescribed according to cognitive or learning style. Since the target user groups of the systems make it difficult to gain balanced samples, we have concentrated on differences depicted by students of the same style; (b) a mapping from a particular style category to a prediction of the most appropriate alternative for this category, could provide a good starting point but it could prove quite restrictive throughout an interaction—experimental data in Section 3.1 showed that students found it useful to have multiple views of the learner model available and had no difficulty in selecting one or more views, with some changing their selections during interaction or using a combination of the alternatives offered. Thus, we suggest that during interaction the learner should have control over the alternatives offered; (c) many style identification measures are based on self-report data, rather than ability tests, in which "there is nothing to prevent learners from answering learning style questions felicitously or according to some construct that implies how they believe that others want them to answer" (Jonassen and Grabowski, 1993, pg. 234). Moreover, the experimental data provided in Section 3.2 showed that often students' perceptions of their study preferences seem to differ from their actual selections, raising questions about the validity of self-report data and the ability of learners to identify a style in advance, which would match their preferences in practice. The validity of self-report data is also linked with style awareness issues. As the experimental study showed, most students working with INSPIRE characterised the approach proposed based on their style as useful and matching their preferences, even if their reports on their study preferences were different. Thus, we suggest that the design of learning environments that accommodate individual differences should also be aimed at the enhancement of learners' style awareness. Informing learners about their interaction behaviour is a promising approach towards this direction, that demands deepening the study of the relationship between a learner's style characteristics and interaction behaviour.

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