Accommodating learning style characteristics in Adaptive Educational Hypermedia Systems

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Abstract. In this paper we build on research reported in the areas of Adaptive Educational Hypermedia and learning styles in order to deal with critical issues influencing the design of adaptation based on the learning style information. In more detail we concentrate on: (*i*) the different learning style categorizations that have been or could be used for modelling learners' learning style in the context of an Adaptive Educational Hypermedia System and the way these could guide the design of adaptation, (*ii*) the adaptation technologies that could better serve learners with different learning styles, (*iii*) the dynamic adaptation of the system and the diagnosis process including the identification of specific measures of learners' observable behaviour which are indicative of learners' learning style preferences.

1 Introduction

As learning styles are a significant factor contributing in learner progress, a challenging research goal is to attempt to represent specific characteristics of learners' learning style within Adaptive Educational Hypermedia Systems (AEHS). Taking into account that many different classifications of learning styles have been proposed in the educational psychology literature, this is a demanding task motivated by the expected learning benefits.

Important decisions underlying the incorporation of learning style characteristics in AEHS demand the synergy of computer science and instructional science, such as: (i) the selection of appropriate categorizations, which are appropriate for the task of adaptation, (ii) the design of adaptation, including the selection of appropriate adaptation technologies for different learning style categorizations and of appropriate techniques for their implementation, (iii) the design of the knowledge representation of such a system in terms of the domain and the learner model, (iv) the development of intelligent techniques for the dynamic adaptation of the system and the diagnosis process of learners' learning style including also the selection of specific measurements of learners' observable behaviour, which are considered indicative of learners' learning style and studying attitude.

The research goal of accommodating learning styles in AEHS design could also be combined with the development of meta-adaptive hypermedia systems capable of selecting the most appropriate adaptation technology following the individual characteristics of the current users and context (Brusilovsky, 2003). To this end, an AEHS should have a number of different adaptation technologies at its disposal and be aware about the limits of applicability of each technology. In this context learning style information can considerably contribute to the decision of the appropriate adaptation technologies for learners with particular profiles, as specific categorizations of learning styles seem to match better with specific adaptation technologies.

In this paper we build on research reported in the literature about different approaches that have been adopted for the design of adaptation based on the learning style information, in order to deal with critical issues for the development of an AEHS based on this information. In more detail we investigate: (*i*) the different learning style categorizations that have been or could be used for modelling learners' learning style in the context of an Adaptive Educational Hypermedia System and the way these could guide the design of adaptation, (*ii*) the adaptation technologies that could better serve learners with different learning styles, and (*iii*) the dynamic adaptation of the system and the diagnosis process including the identification of specific measures of learners' observable behaviour which are indicative of learners' learning style preferences.

2 Learning style information in Adaptive Educational Hypermedia

Designing adaptation based on the learning style information builds on hypotheses about the relationship of learning behaviour with learning style. Such hypotheses are necessary for modelling the learners' learning style in the context of an AEHS. Valuable resource in this context is research conducted in the area of educational psychology about learning styles and the way this characteristic influences learners' behaviour and preferences. A variety of learning style categorizations has been proposed which attempt to associate specific characteristics to different categories of learners and propose instruments and methods for assessing learning style (Riding and Rayner, 1998). Such categorizations could provide the necessary theoretical background for designing the adaptive behaviour of an educational system and guide decisions about what the system should offer to learners with different styles and how to do it.

The last years several AEHS reported in the literature use learning style information as a source of adaptation (see Table II). Several of them build on a theoretical background inspired from the learning style research. The objective of this section is to investigate the way different categorizations of learning styles could support the design of adaptation in terms of specific adaptation technologies. To this end we investigate: (*i*) the learning style categories that have been or could be exploited in AEHS and the way several of them have been used for modelling learners' learning style, and (*ii*) the implications that different learning style categorizations have on the design of different adaptation technologies.

Modelling the learning style information. Sadler-Smith (1997) identified four broad categories of 'learning style' in an attempt to acknowledge and accommodate the range of aspects of individual differences referred in the educational psychology literature in an holistic way: (i) 'cognitive personality elements' such as field dependence and field independence (Witkin et al., 1977), (ii) 'information-processing style' such as the experiential learning cycle (Kolb, 1984) and the associated leaning styles (converger, diverger, accommodator, assimilator), or the related learning styles suggested by Honey & Mumford (1992), activist, reflector, theorist, pragmatist, (iii) 'approaches to studying' such as deep approach, surface approach, strategic approach, lack of direction, academic self-confidence (Entwistle & Tait, 1994), (iv) 'instructional (i.e. learning) preferences' defined as an individual's propensity to choose or express a liking for a particular instructional technique or combination of techniques, such as dependent learners, collaborative learners, independent learners suggested by Riechmann & Grasha (1974). In this paper we use the term 'learning style' as a representative one for all the aforementioned categories.

In an attempt to organise the different approaches adopted in several AEHS reported in the literature, we identified: (*i*) systems that use the learning style information in order to design the content of instruction, and (*ii*) systems that use the learning style information in order to adapt to the learners' 'form' of cognitive activity (i.e. thinking, perceiving, remembering). The first class of systems usually adopt categorizations of learning styles that belong to the 'information-processing style' or 'instructional (i.e. learning) preferences' categories, while systems of the second class adopt categorizations of learning styles that belong to the 'cognitive personality elements' category.

In more detail, the adaptive behaviour of AEHS that belong to the first category concentrate on the type and usually the sequencing of material they offer based on a framework proposed by the authors (ACE, Arthur, MANIC) or based on research studies (Honey & Mumford, 1992), (Felder and Silverman, 1988) about the type of instructional material that learners with different learning style prefer (INSPIRE, CS383).

The systems of the second category, which are developed based on learner's cognitive style, concentrate on the 'form' of cognitive activity (i.e., thinking, perceiving, remembering) that learners usually adopt (Triantafillou et al., 2003; Bajraktarevic et al., 2003). For example, AES-CS (Triantafillou et al., 2003) uses the Field dependence/independence (FD/FI) styles [14]. AES-CS adopts several instructional strategies that accommodate learners' learning style in relation with: the approaches (global versus analytical approach), the control options (program control versus learner control), the contextual organizers (advance organizer, post organizer), the study instructions (provide minimum or maximum instructions), the feedback, and the lesson structure. Also, Bajraktarevic et al. (2003) use the Holist/Serialist learning styles proposed by Pask (1976) which is aligned with the Wholist/Analytics dimension and with the Global/Sequential categorisation (Felder and Silverman, 1988). Following the adopted approach, the system provides learners with different linking structures of the content tailored to their learning style.

Implications for Adaptation Design. The objective of this sub-section is to investigate the way different categorizations of learning styles that focus on different

characteristics of learners could support the design of adaptation in terms of specific adaptation technologies.

Adaptive presentation & curriculum sequencing. Adaptive presentation and curriculum sequencing technologies aim at tailoring the educational content to learners' learning style (adapt the content or its sequencing). These adaptation technologies could better serve learning style categorisations that deal with learners' preferences of instructional material or instructional strategies, such as those that belong at the 'information-processing style' or 'instructional (i.e. learning) preferences' categories. Representative examples of this approach are the systems Arthur, CS383, ACE, and INSPIRE. Arthur and CS383 use multiple types of resources differing in the media they utilize, whilst ACE and INSPIRE adapt the sequencing of different types of resources to different learning style categories following a variety of instructional strategies. In the first case, the alternative styles of instruction that are adopted for learners with different learning style demand the development of multiple types of educational material using different media for each particular section of the course. In the second case multiple types of resources are reused following a different sequencing based on the learner's learning style. This is an alternative to the commonly used approach of rewriting the same content for each learning style category (McLoughlin, 1999).

Adaptive navigation support. The goal of the adaptive navigation support technology is to support the learners in hyperspace orientation and navigation by changing the appearance of visible links. In this context the learning style information could serve as a valuable resource about learners' navigation "habits" and needs. Thus, the design of this technology could be mainly supported by research in the area of learning style categorizations that belong to the 'cognitive personality elements' and deal with the structure and organisation of the contents of instruction, such as the FD/FI dimensions and wholist-analytic dimensions. AES-CS is a representative AEHS that uses the learning style information in order to decide which navigational tools and aids are appropriate in order to help learners organize the structure of the knowledge domain and move accordingly within.

Adaptive collaboration support. Learning style information can also be used as the basis for the construction of groups to support collaborative learning. In the context of AEHS, the goal of the adaptive collaboration support technology (Brusilovsky, 1998) is to use system's knowledge about different users (stored in user models) to form a matching collaborating group. Thus, an interesting approach would be to use the learners' learning style information for organizing learners in groups as this characteristic is considered to influence social interaction. Thus, the design of the adaptive collaboration technology could be mainly supported by categorisations that deal with the social dimension of learners. For example, studies have identified a number of relationships between FD/FI dimension and learning, including the ability to learn from social environments (Witkin et al., 1977). Thus, FI individuals tend to enjoy individualised learning, while FD ones cooperative learning. Also, following Honey and Mumford (1992), groups with full range of learning styles in terms of Activists, Reflectors, Theorists and Pragmatists, exhibit better performance compared to randomly constituted groups.

Moreover, different learning style categorizations may assist the design of more than one adaptation technologies such as the verbal-imagery dimension. This learning style dimension interacts with mode of presentation of information (for example textual/verbal or diagrammatic/pictorial modes) and thus it may assist the design of the instructional material in the context of the adaptation presentation technology as well as the design of navigational aids in terms of the adaptive navigational support technology. Although experimental results are promising (see next section) more research has to be conducted in order to learn more about the relationships between learning styles, learning behavior in terms of observable patterns of learners' activity and possible adaptation approaches.

Open Issues. Although several learning styles categorizations have been exploited in AEHS, there are many more that have not been considered yet such as those that belong in the category of 'approaches to studying'. What is important in exploiting different learning style categorizations in AEHS is their potential to support and enhance adaptation providing appropriate guidance for AEHS developers. Thus, the wide range of learning style categorizations should be investigated through the ways each categorization could assist the design of the different adaptation technologies or inspire the design of new ones. This research goal has two different values both for the educational psychology area to evaluate the effectiveness and the validity of matching instructional methods to learners' styles and preferences in e-learning, and the adaptive educational hypermedia area to improve the effectiveness and efficiency of adaptation.

3 Evaluating the benefits from designing adaptation based on learning styles

Although several AEH systems that use learning 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 prove the effectiveness of the adopted approaches. The goals of such studies concentrate on the effectiveness and/or efficiency of adaptation, which are measured through learners' performance, learning time, navigation patterns, learners' subjective estimation. Different dimensions that are considered in these studies are: (*i*) the relationship between matching and mismatching instructional approaches with learners' learning style (Ford and Chen, 2001; Bajraktarevic et al., 2003) (*ii*) the learning performance and learning time of learners with different learning style in matched sessions (Triantafillou et al., 2003); (*iii*) the navigation patterns of learners with different profiles in matched sessions (Papanikolaou et al., 2003).

Ford and Chen (2001) investigated if the matching of instructional presentation strategies and learners' learning style is linked with improved learning performance. They report that learners of the FD/FI styles who learned in matched conditions scored significantly higher in tests measuring their conceptual knowledge but not in performing practical tasks. Following the authors, these results provide evidence about the learning benefits coming from matching learners' learning style with instructional presentation strategies and indicate the need to take into account

qualitative characteristics of expected learning outcomes such as learning, recall and application of conceptual knowledge, in designing adaptation. Triantafillou et al. (2003) conducted a small group evaluation in order to measure the effectiveness and efficiency of the instructional approaches adopted in AEC-CS for FD/FI learners. They found that all learners' performance was increased after instruction in matched conditions. In more detail, they found that the FI learners had better results than the FD ones, although FD learners were improved more than the FI ones. Furthermore, as learners spent less than an hour to complete the courseware (which was designed to correspond to a typical lecture hour), the adopted approach was considered efficient. In this study learners reported their satisfaction from the initial adaptation as well as from the fact that the system was completely controllable by them. In another study reported in (Papanikolaou et al., 2003), the authors analyzed learners' studying behaviour (time spent and hits on resources) and navigation traces by the different learning style categories proposed by (Honey and Mumford, 1992). The main aim of this study was to provide evidence about the way learners that belong to different learning style categories select and use educational resources that are considered beneficial for their styles in INSPIRE. Although this was a pilot study, the results were encouraging, confirming the initial hypotheses on which the presentation and sequencing of resources was based. Lastly the main aim of the study reported in (Bajraktarevic et al., 2003) was to evaluate the effectiveness and the efficiency of the adopted adaptation approach. Effectiveness was measured through learners' performance in matched and mismatched learning-style sessions (Holist/Serialist learning styles), whilst efficiency through learners' browsing time in matched and mismatched learning-style sessions. Learners' performance was significantly higher in matched sessions for all learners, whilst there was not significant difference between browsing times for the matched / mismatched groups.

4 Diagnosis of learning style: critical issues influencing adaptation

Vermunt (1996) conceptualises learning styles as consistent patterns of learning activities that are systematically linked to learning beliefs and motivational orientations. Thus, learning styles are not taken to be invariable (at least many of the proposed categorisations), as they may be influenced by the particularities of the learning context and its demands. Along this line, in the context of AEHS, a critical issue for recognising changes in learners' needs and preferences is to determine measures of learners' observable behaviour which are indicative of learners' learning style preferences. Thus, incorporating the learning style information in the context of AEHS requires, apart from a theoretical background, a qualitative analysis (categorization) of learners' steps and/or selections (features/tools of the system that they access/use) as they interact with the system. This information is also valuable in order to study the extent to which the hypotheses about learners' learning style preferences, match their learning behaviour as it is depicted through their actual navigation through the interaction.

Student diagnosis is the process of inferring students' internal characteristics from their observable behavior (VanLehn, 1988). An AEHS, due to the restricted

communication channel, is only able to directly obtain raw measurements, by monitoring the interaction with the learner, aiming to identify learners' changing needs and maintain the current state of the learner. Thus, critical issues that should be considered in designing the diagnosis process of learners' learning style are: (*i*) the initialisation of the learner model, (*ii*) the selection of appropriate measures to serve as indicators of learners learning style preferences, and (*iii*) the qualitative analysis of learners' observable behaviour that could support the dynamic adaptation of the system during the interaction.

In this context diagnosis should exploit the two methods usually used for assessing learners' learning preferences (Riding and Rayner, 1998): self-report measures through questionnaires, and observed behaviour choices. Especially the first approach is usually adopted for the *initialisation of the learner model*, whilst the second one for the dynamic adaptation of the system through the interaction. Following the first approach, several systems use specially designed psychological tests designed for particular learning style categorisations (INSPIRE, AES-CS), whilst others use interviews in order to let the learners decide on specific aspects of their learning style preferences (ACE). During the interaction, several systems allow the learners to directly manipulate their learning style expressing their own point of view about themselves and consequently about system adaptation (INSPIRE, AES-CS).

Through the interaction with the system, learner's observable behaviour is, in many cases, the basis for the diagnosis of certain characteristics of the learner such as his/her preferences of the learning material. In such cases, the dynamic adaptation of the system is based on real data coming from learners' interaction with the system. For example, in ACE, the dynamic adaptation of the instructional strategy is based on information coming from monitoring learner's requests on learning materials, as well as on the success of the currently used strategy. The latter is mainly determined by learner's performance in the final tests; repeated occurrences of high performance raise the preference value of a strategy until a threshold is reached. Also, Arthur dynamically adapts the instructional style according to learner's performance in the tests s/he submits. For example, in case the learner scores 70% in a quiz of a concept, then s/he will be provided with material of alternative instructional style; otherwise, the instructional style currently used is supposed to match the learner's learning style. Lastly, MANIC uses machine learning techniques in order to identify learners' preferences by observing his/her interactions with the system.

The selection of measures on which dynamic adaptation is based, is a significant factor influencing its effectiveness. For example, is learners' performance on tests or time spent on educational resources, adequate measures for learners' changing learning style preferences during the interaction? What about the individual characteristics of the learning style categorisation adopted for modelling learners' style, or the hypotheses on which system adaptation is based about learners' style? For example in case of the FD/FI categorization the way learners navigate is more appropriate as an indicator of their style than the specific type of material they select. On the other side this may be a valuable information about categorizations such as Verbalisers / Imagers or Activists / Theorists / Pragmatists / Reflectors. Thus, a critical issue in designing dynamic adaptation based on learners' observable behaviour is to identify which learners' actions are indicators of their style, and

should be considered in assessing their changing needs and preferences during interaction.

To this end, valuable resources could be studies reported in the literature investigating which *measures of learners' observable behaviour* are indicative of their learning style preferences and learning behaviour. Indicators that have been investigated for several learning style categorizations are: (*i*) navigational indicators (number of hits on educational resources, preferable format of presentation, navigation pattern); (*ii*) temporal indicators (time spent in different types of educational resources proposed); (*iii*) performance indicators (total learner attempts on exercises, assessment tests) (Reed et al., 2000; Lu et al. 2003; Souto et al., 2002; Papanikolaou et al, 2003). This is a promising research direction which may help us develop deeper knowledge of the complex interactions between learners and educational content and further inspire new approaches in the design of AEHS.

4 Conclusions

Especially in a web-based educational system, where the variety of learners taking the same course is much greater, a challenging goal in the design, development and delivery of learning could be the accommodation of learners' individual differences in terms of their learning styles. Towards this end, critical issues on which research in AEHS should focus are: (i) the design of adaptation based on the learning style information (what the system should offer to learners with different styles and how to do it in terms of deciding which adaptation technologies could better serve the aims of the adaptation), (*ii*) the selection of appropriate measures of learners observable behaviour which could serve as indicators of learners learning style preferences, (*iii*) the qualitative analysis of these observable measures that could support the dynamic adaptation of the system during the interaction.

To the above research goals valuable resources are the different categorizations of learning styles proposed in the area of educational psychology. Such information may: (*i*) assist in the design of AEHS which accommodate learners' styles and preferences; (*ii*) contribute to the enhancement of the pedagogical perspective of such systems; (*iii*) assist the evaluation of the effectiveness and efficiency of adaptation; (*iv*) provide directions for future research into the validity of matching instructional methods to learners' styles and the effectiveness of adaptation.

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Table II. Comparison of AEHS that use learning style as a source of adaptation

System	Domain	Learning Style Model	Adaptation based on Learning Style	Diagnosis Approach & Dynamic Adaptation
ACE (Specht & Opperman, 1998)	Domain Independent	Learning style preferences: *preferences about sequencing of learning materials*	Sequencing of learning materials according to a particular teaching strategy (learning by example, reading texts or learning by doing), based on learner's interests and material preferences.	Dynamic adaptation of the teaching strategy is based on info coming from monitoring learners' requests on ed. material, and on the success of the currently used strategy (determined by learner's performance in tests).
CS383 (Carver et al., 1999)	Computer Systems	Sensing/intuitive, visual / verbal, and sequential/global (Felder and Silverman, 1988)	Lesson media elements presented in a sorted list ranked from the most to least conducive based on learners' learning style.	During the first lesson learners submit the questionnaire proposed by (Solomon, 1992) to identify their learning style.
Arthur (Gilbert and Han, 1999)	Computer Science Programming	Learning style preferences: *style of instruction during which learners exhibit satisfactory performance*	Alternative styles of instruction differ in the type of media they utilize: visual-interactive, auditory-text, auditory-lecture, and text style.	Dynamically adapts the instructional style according to learner's performance in the tests s/he submits.
AES-CS (Triantafillou et al., 2003)	Multimedia Technology Systems	Field dependent / Field Independent (Witkin et al., 1997)	Adapt amount of control (program vs. learner control), contextual organizers (advance vs. post), instructional support, navigational tools and feedback to assessment questions.	Learners submit the Group Embedded Figures Test (GEFT) questionnaire. Direct manipulation of LM (Learner Model).
INSPIRE (Papanikolaou, et al., 2003)	Computer Architecture	Activists, Pragmatists, Reflectors, Theorists (Honey & Mumford, 1992)	Adapt the method and order of presentation of multiple types of educational resources within educational material pages.	Learners submit the questionnaire proposed by (Honey & Mumford, 1992) or they define their learning style. Direct manipulation of LM.
MANIC (Stern & Woolf, 2000)	Domain Independent	Learning style preferences: *media (graphic, text), type of instruction, level of content abstractness, ordering of different types of content*	Presentation of content objects using *stretchtext* which allows certain parts of a page to be opened or closed. Sequencing of content objects for a concept based on learner's preferences.	The system dynamically adapts the content presentation by observing learner's interactions with the system.