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Analysis of learners' navigational behaviour and their learning styles in an online course

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Abstract

Providing adaptive features and personalized support by considering students' learning styles in computer-assisted learning systems has high potential in making learning easier for students in terms of reducing their efforts or increasing their performance. In this study, the navigational behaviour of students in an online course within a learning management system was investigated, looking at how students with different learning styles prefer to use and learn in such a course. As a result, several differences in the students' navigation patterns were identified. These findings have several implications for improving adaptivity. First, they showed that students with different learning styles use different strategies to learn and navigate through the course, which can be seen as another argument for providing adaptivity. Second, the findings provided information for extending the adaptive functionality in typical learning management systems. Third, the information about differences in navigational behaviour can contribute towards automatic detection of learning styles, helping in making student modeling approaches more accurate.

Keywords learning management systems, learning styles, navigational behaviour, sequential analysis

Introduction

Learning management systems (LMSs), also known by terms such as course management systems or e-learning platforms, are commonly used in computer-assisted learning, especially for open and distance learning provided by companies, universities and other educational institutions. According to Alias and Zainuddin (2005), a learning management system can be defined as 'a software application or Web-based technology used to plan, implement, and assess a specific learning process'. Examples of LMSs include systems such as Blackboard (2008), Moodle (2008), and Sakai (2008). LMSs provide teachers with many features to create, manage and administrate online courses, allowing them to include different kinds of learning objects/activities such as learning material, forums, quizzes, examples, and so on, and facilitating administrative issues such as enrolment, grading and monitoring the learners' progress and performance. While these systems aim at supporting teachers and administrators, they typically do not focus on considering the individual differences and personal needs of learners, providing only little, or in most cases, no intelligent support or adaptive features for learners.

However, the individual differences of learners play a central role in traditional as well as computer-assisted learning. Each learner has individual needs and characteristics such as different prior knowledge, cognitive

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abilities, learning styles, motivation and so on. These individual differences affect the learning process and are the reason why some learners find it easy to learn in a particular course, whereas others find the same course difficult (Jonassen & Grabowski 1993).

In this paper, we focus on the consideration of learning styles. The field of learning styles is complex, and although lot of research has been conducted, some important questions are still open. Coffield *et al*. (2004) pointed out several controversial issues, including the existence of many different views, definitions, and models of learning styles, the reliability and validity of instruments for identifying learning styles, the feasibility and effectiveness of incorporating learning styles in education, and the way learning styles should be used in education. While Coffield *et al*. (2004) concluded that learning styles are often misused and are limited in what they can achieve, many other researchers argue that the consideration of learning styles is an important factor in education (e.g. Felder & Silverman 1988; Cristea & Stash 2006; Lu *et al*. 2007). Especially in the last years, several research works have been conducted that support this argument. Examples are the development of adaptive systems such as the two-source adaptive learning system (TSAL) (Tseng *et al*. 2008), the web-based educational system with learning style adaptation (WELSA) (Popescu 2008) and an add-on to LMSs (Graf & Kinshuk 2007). The evaluation of these systems showed that considering learning styles can decrease learners' effort in terms of time required for learning and increase overall learner satisfaction. Furthermore, research towards improving the identification of learning styles has been conducted, aiming at making student modeling more accurate by developing automatic approaches (e.g. Cha *et al*. 2006; García *et al*. 2007; Graf *et al*. 2008).

This paper aims at contributing to the field of adaptivity based on learning styles in computer-assisted learning by analysing how learners use and navigate through a typical online course. The course was taught in Moodle (2008), which is a well-known LMS with more than 45 000 registered sites worldwide (Moodle Sites 2008).

Navigational behaviour refers to how learners navigate through the course and in which order they visit different kinds of learning objects and activities. The order in which learners prefer to take in and learn from specific kinds of learning material and activities, as well as in which order and priority these different kinds of learning material and activities should be presented for supporting learners with different learning styles is a key aspect of most learning style theories. Furthermore, adaptive navigation support, in terms of recommending learners a suitable way through the learning material and activities, is one of the two main ways for adding adaptive functionality to learning systems (Brusilovsky 2001).

The aim of this study is to investigate how learners with different learning styles use the course differently with respect to navigational behaviour. Findings about such differences have three contributions to the research area of computer-assisted learning, especially to adaptive computer-assisted learning. First, they show that learners with different learning styles prefer to go through an online course in different ways and therefore, give another supporting argument for providing adaptivity based on learning styles in learning systems. Second, the information about how learners with particular learning styles prefer to navigate through the course, derived from a data-driven approach, can be used as additional source for providing adaptivity or extending adaptive features in terms of tailoring courses to the learners' preferences or providing suggestions about which kinds of learning objects or activities should be conducted next if learners need some guidance. Third, the differences can be used as valuable information for detecting learning styles automatically. While recent research works (such as Cha *et al*. 2006; García *et al*. 2007; Graf *et al*. 2008) have focused on developing an approach for automatic detection of learning styles from students' behaviour during an online course, these approaches do not consider the navigational behaviour so far, which can be used as an additional source in order to make the automatic detection process of learning styles more accurate.

In the next section, the study design is described. Section 3 presents the results of the study, describing the differences in navigational behaviour of students with different learning styles. Section 4 discusses the results and concludes the paper.

Study design

This section introduces the study design. The first section deals with the selected learning style model. Subsequently, details about the investigated course and

data are shown. The aims of this study are concretized in the subsequent section by introducing the investigated assumptions with respect to navigational behaviour. The last section introduces the method of analysis.

Felder–Silverman Learning Style Model

As mentioned earlier, many learning style models exist in literature such as the learning style model by Kolb (1984), Honey and Mumford (1982), and Felder and Silverman (1988). Each proposes different descriptions and classifications of learning styles. This work focuses on the Felder–Silverman Learning Style Model (FSLSM) for several reasons. FSLSM combines several major learning style models such as the learning style model by Kolb (1984), Pask (1976) as well as the Myers-Briggs Type Indicator (Briggs Myers 1962). Although the dimensions themselves are not new, the way in which they are combined and describe the learning styles of students is new. Most other learning style models classify learners into few types, whereas Felder and Silverman describe the learning style of a learner in more detail, distinguishing between preferences on four dimensions using values between +11 and –11 for indicating the learners' preferences on each dimension. By using scales rather than types, the strengths of learning style preferences can be described, enabling the model to distinguish between strong and weak preferences for a particular learning style. Furthermore, FSLSM is based on the concept of tendencies, indicating that learners with a high preference for certain behaviour can also act sometimes differently. By incorporating the concept of tendencies, the description of learning styles considers also exceptions and extraordinary situations.

FSLSM has often been used in research related to learning styles in advanced learning technologies. According to Carver *et al*. (1999), 'the Felder Model is most appropriate for hypermedia courseware' (p. 34). Kuljis and Liu (2005) confirmed this by conducting a comparison of learning style models with respect to their application in e-learning and Web-based learning systems. As a result, they also suggest FSLSM as one of the most appropriate model, arguing that it fits well for fulfilling the adaptability that tailors to learning differences and individual needs.

FSLSM characterizes each learner according to four dimensions: active/reflective, sensing/intuitive, visual/verbal and sequential/global. *Active* learners learn by trying things out and working together with others, whereas *reflective* learners learn by thinking things through and reflecting about them, and they prefer to learn alone. *Sensing* learners like to learn from concrete material-like examples, tend to be more practical and are careful with details, whereas *intuitive* learners prefer to learn abstract material, like challenges and are more innovative. *Visual* learners remember best what they have seen, whereas *verbal* learners get more out of words, regardless of whether they are spoken or written. *Sequential* learners learn in linear steps, prefer to follow linear, stepwise paths and be guided through the learning process, whereas *global* learners learn in large leaps and prefer a higher degree of freedom in their learning process.

Felder and Soloman developed the Index of Learning Styles (ILS) (Felder & Soloman 1997; Felder & Spurlin 2005), which is a 44-item questionnaire for identifying learning styles based on the FSLSM. As a result, the questionnaire provides four values, representing the learners' preference on each learning style dimension expressed by values between +11 and –11. Using the active/reflective dimension as an example, +11 means that a learner has a strong preference for active learning, whereas –11 states that a learner has a strong preference for reflective learning.

Several studies have been conducted in order to test the reliability and validity of the ILS questionnaire. For example, a study by Zywno (2003) showed moderate to strong test–retest reliability with correlation coefficients between 0.505 and 0.683 when using an interval of eight months. Another study reported coefficients between 0.60 to 0.78 for a seven-month interval (Livesay *et al*. 2002). Regarding internal consistency reliability, several studies (Livesay *et al*. 2002; Felder & Spurlin 2005 citing Van Zwanenberg *et al*. 2000; Zywno 2003) showed that Cronbach's alpha coefficients met acceptable limits for all dimensions, with alpha values between 0.51 and 0.76, apart of one result by Van Zwanenberg *et al*. (2000), which showed an alpha value of 0.41 for the sequential/global dimension. The same studies also analysed inter-scale orthogonality and showed that three of the four dimensions are reasonably orthogonal, but the sensing/intuitive and sequential/global dimensions showed a moderate degree of association. Studies that reported about the distribution of learning styles in different disciplines

support the claim of construct validity, showing that learners in similar disciplines have similar distribution of learning styles as summarized by Felder and Spurlin (2005). Furthermore, Zywno (2003) analysed construct validity by comparing ILS results over time, showing no significant differences and therefore, supporting the construct validity of the ILS questionnaire. Overall, most studies lead to the conclusion that the ILS questionnaire may be considered as reliable, valid and suitable.

Course

This study is based on a course about object-oriented modeling (OOM) that was taught to undergraduate students in the second semester of Information Systems and Computer Science at a university in Austria. The course ran for seven weeks. It was composed of a lecture and a practical part where students had to submit five assignments. The whole course was managed via Moodle.

The online course had seven chapters, including an introduction chapter, five chapters about the main concepts of OOM and one chapter about the practical usage of OOM. The course was composed of commonly used kinds of learning objects/activities in online learning. Furthermore, Moodle provided students with overview pages in order to see all kinds of particular learning objects/activities, such as all resources and all quizzes. These pages were included in the analysis in order to get a complete understanding about the students' navigational behaviour.

The kinds of investigated learning objects/activities included the following:

1. *Overview page:* this page was the main course page and shows all learning objects/activities of the course.
2. *Forum:* the course included a discussion forum that students could use for asking course-related questions to the teachers or their peers.
3. *Outlines:* these pages provided the students with a brief overview of the respective chapters.
4. *Content objects:* these objects were used to present the content of the course. Overall, the course included 424 content objects.
5. *Conclusions:* each chapter ended with a conclusion that summarized the key issues of the chapter.
6. *Lecture notes:* each chapter included one or two files that provided the outline, all content objects and the conclusions of a chapter in print version.
7. *Examples:* examples aimed at illustrating the theoretical content in a more concrete way. Overall, the course included 25 examples, five for each of the main chapters.
8. *All-resources page:* the all-resources page was a page offered by Moodle, presenting all resources provided in the course, which included all outlines, content objects, conclusions, lecture notes and examples. The page was accessible from the overview page of the course.
9. *Self-assessment* (SA) tests: SA tests included theoretical questions where students could check if they understood the theoretical concepts of the learning material. Each chapter included the possibility to conduct an SA test. Overall, the seven tests included 114 questions, where for each test, five questions were randomly presented to the student from the pool of questions of the respective chapter. Students were free to perform SA tests as often as they wished. In this study, two different states were distinguished in the process of conducting an SA test: viewing the questions of the test and submitting the answers to the questions. After finishing the SA test, the correct results were shown to the student together with the answers the student had given, and for each question, a link to the content object was presented, which provided more information about the correct answer.
10. *Exercises:* these elements served as practice area, consisting of practical questions where students had to interpret pre-defined solutions or develop new solutions to a given problem, and therefore, they could check if they were also able to apply the theoretical knowledge. For each of the five main chapters, five exercises with several questions were provided. Overall, the exercises included 181 questions. Again, two different states were distinguished: viewing exercises and submitting answers.
11. *All-quizzes page:* similar to the all-resources page, this page was provided by Moodle, accessible via the overview page, and presented all SA tests and exercises to the students on one page.
12. *Assignments:* students had to submit five marked assignments offline. However, in Moodle, they could find the instructions for the assignments.

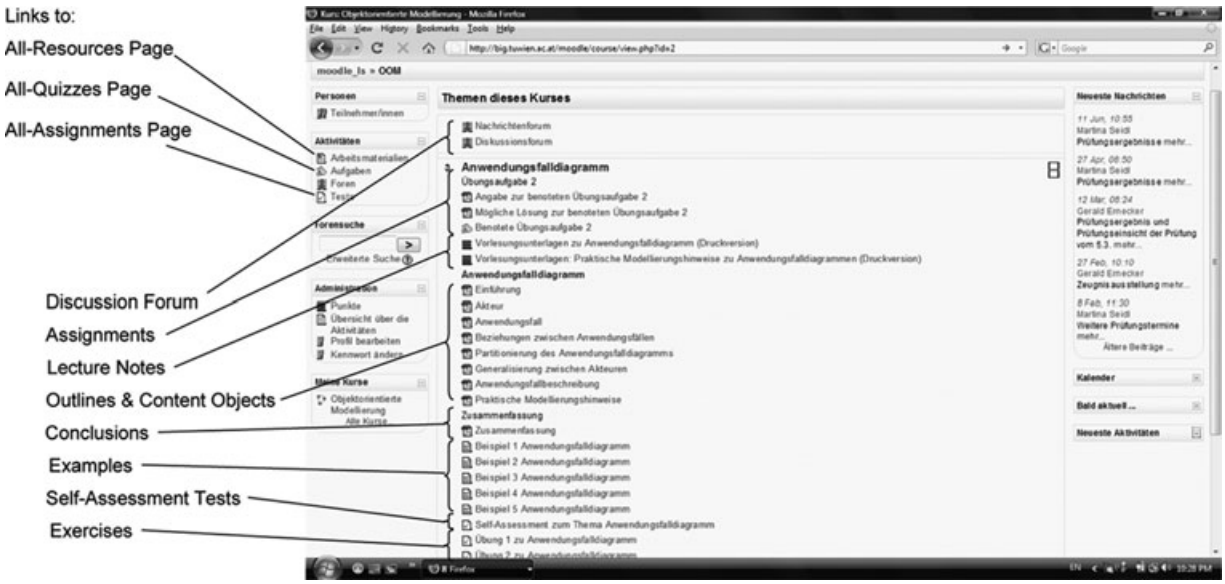

Fig 1 Overview page of the course.

13 *All-assignments page:* similar to the all-resource page, this page was provided by Moodle, accessible via the overview page, and presented all assignments on one page.

14 *Others:* the course also included for students some other features that were not related to learning and therefore summarized in this category. Examples include logging in, changing one's password, doing other changes in the student profile and looking at other students' profiles.

Figure 1 shows the overview page of the course with its links to the all-resources page, the all-quizzes page and the all-assignments page as well as the learning objects/activities for each chapter.

The assignments had to be performed in groups of two. A few days after the submission, each student had to present the solution individually and had to answer questions about it. At the end of the course, each student had to successfully complete a written exam. Although parts of the assignments were performed in groups of two, the course was designed in a way that all students needed to learn everything and they were examined on all topics; hence, the course was appropriate for investigation of individual learning.

Students were required to register in Moodle because of administrational issues of the course. However, the usage of Moodle for learning was voluntary. Students' marks were only based on the results of their assignments and the final exam.

Data

One hundred and twenty-seven students participated in the study. When registering in Moodle, they filled out the ILS questionnaire (Felder & Soloman 1997; Felder & Spurlin 2005) so that their learning styles could be identified and stored in Moodle. Furthermore, Moodle has a tracking mechanism that stores the paths students took in the course and from which all necessary data for this study with respect to the students' navigational behaviour could be extracted.

In order to use students' data in this study, three requirements had to be fulfilled. First, the time students spent to fill out the ILS questionnaire was recorded. Data of students who spent less than five minutes on the ILS questionnaire were discarded because the detected learning styles were considered as not reliable enough. Accordingly, data from 41 students were discarded. This relatively high number can be explained by the lack of the students' motivation to fill out the questionnaire. Second, only data from students who submitted at least three assignments were included, which was a requirement for passing the course. This requirement was chosen in order to exclude students who dropped out because the data from those students

Table 1. Distribution of learning styles.

Learning styles	Active	Reflective	Sensing	Intuitive	Visual	Verbal	Sequential	Global
Number of students	40	35	46	29	64	11	34	41

would not show representative behaviour. Ten students did not meet this requirement, whereby data from two of them were already discarded because of the first criterion. However, nine out of these 10 students just registered in the course but did not submit even one assignment. Third, only data from students who took part in the final exam were included, which was also a requirement for passing the course. This requirement is important because it ensures that for all students, the preparation for the final exam is included in the data. Sixteen students did not meet this requirement, including the ten students who already did not submit enough assignments and the three students who met the second but not the first requirement. Overall, data from 75 students out of 127 were used for this study.

Table 1 shows the distribution of learning styles for all dimensions. Since only 11 out of the 75 students had a verbal learning style, this dimension was excluded from this analysis. The low number of students with a verbal learning style as well as their mainly weak preferences for verbal learning (only two students had a value of –5, all others had values of –3 or –1) would lead to unreliable results when comparing visual and verbal navigational behaviour. Therefore, only the active/reflective, sensing/intuitive and sequential/global dimension were investigated.

Investigated assumptions

This study focuses on several assumptions about the different navigational behaviour of learners with different learning styles in an online course. These assumptions are derived from FSLSM, which describes how learners prefer to behave in general learning situations. In the following subsections, the investigated assumptions are described in more detail for each learning style dimension.

Active/reflective dimension

According to FSLSM, active learners are characterized as learners who like to communicate and discuss with others, while reflective learners prefer to observe and work alone. The discussion forum can therefore be a relevant element for finding differences in the students' navigational behaviour. Active learners are expected to navigate frequently to the forum in order to be up to date with new postings and maybe answer them. On the other hand, reflective learners are expected to use the forum more for reading and searching for information in the postings. The different preferences of active and reflective learners might be visible in their navigation patterns when looking at how often learners go from the overview page to a forum page and from the forum page back to the overview page.

Another characteristic of active learners is that they like to try things out rather than reading only the learning material. This preference can be reflected by how they use exercises and how they navigate through the learning material. For exercises, active learners are expected to try exercises again and again by re-submitting them, which is presented in the system by finishing exercises repeatedly. Regarding navigating through the learning material, another assumption is that active learners are more interested in the summary of the chapter than reading each content object and therefore more often jump from content objects to the conclusions.

Another element that might show different navigational behaviour for learners with active and reflective learning styles are the SA tests and their feedback links that lead students to respective content objects for getting further information about the correct answer to a question. While both active and reflective learners are expected to use this feedback option frequently, reflective learners are expected to be more interested in reflecting about the results and therefore continue with the SA tests after visiting the content object, checking the results of other question/answer pairs in the conducted SA test or starting a new SA test. On the other hand, active learners are expected to leave the SA area more often and continue with something else.

Sensing/intuitive dimension

Similar to active and reflective learners but because of different preferences, the discussion forum can indicate differences in behaviour patterns for sensing and intuitive learners. Sensing learners are characterized as

patient and more careful with details, while intuitive learners tend to be more creative, like challenges and are not that careful with details. Because many of the postings in the forum deal with clarifying the content or details about the assignments, sensing learners are expected to use the forum more for searching information and reading messages about a specific topic. On the other hand, intuitive learners are expected to use the forum frequently but more for checking new postings rather than browsing through postings in order to find information. Therefore, navigation patterns, including going from the overview page to a forum page and from a forum page to the overview page, can show differences in sensing and intuitive learners' behaviour.

According to FSLSM, sensing learners prefer concrete material and have difficulties with abstract content. Therefore, conclusions of the learning material are expected to be a relevant source for sensing learners, and sensing learners are expected to access conclusions explicitly from the all-resources page and go from conclusion to conclusion more often than intuitive learners.

Another characteristic of sensing learners is that they prefer to be well-prepared for solving problems with already learnt procedures and like to apply the theoretical knowledge in practical settings. This characteristic can lead to two navigation patterns. First, sensing learners are expected to access quizzes (SA tests and exercises) more often and explicitly through the all-quizzes page, which can be seen from how often they go from the overview page to the all-quizzes page. Second, sensing learners are expected to use the link for getting feedback about answers at the SA tests frequently, following the link to the respective content object and then continuing, going through the answers or starting a new test. Intuitive learners, on the other hand, are not so patient with details and do not like repetition and tasks where they have to apply the same standard procedures. Therefore, they are expected to use the feedback links less often, and if they use them, then maybe do not return to the SA area. Furthermore, intuitive learners are expected to go more often from one SA test to another without solving/finishing the first one, taking the assessment not that seriously.

Sequential/global dimension

According to FSLSM, it is important for global learners to get an overview about the learning material. Respectively, outlines are important for global learners. With respect to navigational behaviour, global learners are therefore expected to go more often through the outlines of all chapters, indicated by going from outline to outline. Furthermore, conclusions can help global learners to get an overview. Therefore, they are expected to go through the conclusions of all the chapters, indicated by going from conclusion to conclusion.

Furthermore, the learning material seems to be an important feature with respect to distinguishing the navigational behaviour of sequential and global learners. According to FSLSM, sequential learners tend to go through the learning material step by step, while global learners more often jump to other learning objects without using the recommended sequence. Therefore, sequential learners are expected to go more often from one content object to another. On the other hand, global learners are expected to jump more often from content objects to conclusions and outlines.

Another difference in the behaviour of sequential and global learners is expected for the usage of SA tests and the feedback links. Because sequential learners prefer to go through the material in a way the teacher (or system) recommended to go, they are expected to came back more often to the results page of the SA tests, continuing reading their results or performing another test. On the other hand, global learners prefer to go through the learning material in a non-sequential order, and therefore are expected to more often leave the SA area and go somewhere else.

Statistical analysis

For finding differences between the behaviour of students with different learning styles, for each learning style dimension, students were divided into two groups based on their results of the ILS questionnaire using a threshold of 0. In order to analyse the navigational behaviour and find out in which sequence students with particular learning styles typically go through the course, lag sequential analysis (Bakeman & Gottman 1997) was conducted for each learning style (e.g. active, reflective, sensing and so on) based on frequency data of all kinds of learning objects/activities described in the course section above. Sequential analysis has been used in similar contexts when analysing the behaviour of learners (e.g. Hou *et al*. 2008; Sung *et al*. 2008). It tests the statistical significance of behaviour patterns (e.g. going from one kind of learning object to another) by

calculating *Z*-scores from frequency data. These *Z*-scores identify the probability for a particular behaviour pattern to be statistically significant. Using a significance level of 0.05, a *Z*-score is significant if it is higher than +1.96. In order to find differences in the students' navigational behaviour according to the investigated assumptions, the *Z*-scores of the relevant behaviour patterns are compared for both learning styles of the same learning style dimension (e.g. active and reflective) with respect to their significance.

Results

This section presents the results of our study. In Appendix A, a table about the results of the sequential analysis is provided for each of the three investigated learning style dimensions, giving information about the frequencies of transition between all learning objects/activities as well as their significance. Table 2 summarizes the results of the analysis with respect to each assumption, indicating significant results with an asterisk.

From the results, it can be seen that an often used path for active learners was to go from the overview page to the forum and from the forum back to the overview page, while for reflective learners, this sequence is not found as significant and the only significant way to the forum is found to be from another forum page. Therefore, conclusions can be drawn that active learners went more frequently to the forum but checked only few pages there, while reflective learners seem to go less frequently to the forum, but if they are there they read many postings. Furthermore, the results show that re-submitting an exercise and jumping from content objects to conclusions are typical navigation patterns for active learners but not for reflective learners. In addition, the results show that reflective learners typically return to the SA area after viewing feedback, while active learners choose this path only seldom. All these results are in agreement with FSLSM and confirm our assumptions formulated in the investigated assumptions mentioned earlier.

Similar to active and reflective learners, the results show that sensing and intuitive learners have different behaviour with respect to the discussion forum. The path from the overview page to the forum and from the forum back to the overview page is more frequently used by intuitive learners, while for sensing learners, these paths are not typically used. Therefore, a conclusion can be drawn that intuitive learners preferred to go more frequently to the forum but checked only few pages, while sensing learners went to the forum less frequently but check more pages once they were there. Furthermore, the results show that accessing conclusion pages from the all-resources page, accessing the all-quizzes page from the overview page and returning to the SA area after visiting the content objects suggested as feedback are typical navigation patterns for sensing learners but not for intuitive learners. On the other hand, for intuitive learners, the results show that they significantly more often go from one SA test to another without finishing the first one, while this is a seldom used navigation pattern for sensing learners. All these findings are in agreement with FSLSM and our assumptions described earlier. However, one of our assumptions could not be confirmed, dealing with the preference of sensing learners to go from one conclusion page to another. Going from conclusion to conclusion is a typical behaviour for both sensing and intuitive learners and therefore does not indicate a difference between a sensing and intuitive learning style.

With respect to the sequential/global dimension, the results show that going from conclusion to conclusion as well as jumping from content objects to conclusions and outlines are significant navigation patterns for global learners but are only seldom used by sequential learners. On the other hand, the results show that sequential learners typically return to the SA area after viewing content objects as feedback, while for global learners, this is a seldom used path. All these findings are in agreement with FSLSM and our assumptions. For two patterns, we did not find our assumptions confirmed. These assumptions deal with going from content objects to content objects, which was considered to be significant for sequential learners but not for global learners, and going from outline to outline, which was considered to be significant for global learners but not for sequential learners. However, for both sequential and global learners, these patterns are significant, indicating that going from content to content and from outline to outline is an often used pattern by learners with sequential and global learning style.

Discussion and conclusions

The results of this study showed that most of the investigated assumptions could be confirmed, indicating differences in the students' navigational behaviour

Table 2. Results of sequential analysis of investigated assumptions.

Assumptions	From	To	*Z*-scores			Assumption confirmed
			Active (reflective)	Sensing (intuitive)	Sequential (global)	
Active and reflective learners show differences in their navigational behaviour since:						
Only for active learners, going from the overview page to the forum and from the forum back to the overview page are significant behaviour patterns.	Overview page; Forum	Forum; Overview page	2.02* (–0.02); 2.52* (0.15)			✓ ✓
Only for active learners, re-submitting exercises is a significant behaviour pattern	Exercises finished	Exercises finished	5.47* (0.04)			✓
Only for active learners, jumping from content to conclusions is a significant behaviour pattern.	Content	Conclusion	4.00* (1.23)			✓
Only for reflective learners, returning to SA area after feedback is a significant behaviour pattern.	Content	SA test visited	–1.43 (7.07*)			✓
Sensing and intuitive learners show differences in their navigational behaviour since:						
Only for intuitive learners, going from the overview page to the forum and from the forum back to the overview page are significant behaviour patterns.	Overview page; Forum	Forum; Overview page		0.02 (2.92*); 0.55 (2.94*)		✓ ✓
Only for sensing learners, accessing conclusions from the all-resources page is a significant behaviour pattern.	All-resources page	Conclusion		4.58* (0.97)		✓
Only for sensing learners, going through conclusions is a significant behaviour pattern.	Conclusion	Conclusion		15.83* (4.50*)		×
Only for sensing learners, accessing quizzes by going from the overview page to the all-quizzes page is a significant behaviour pattern.	Overview page	All-quizzes page		2.07* (0.59)		✓
Only for sensing learners, returning to SA area after feedback is a significant behaviour pattern.	Content	SA test visited		7.87* (–2.97)		✓
Only for intuitive learners, going from one SA test to another without solving it is a significant behaviour pattern.	SA test visited	SA test visited		–3.12 (2.43*)		✓
Sequential and global learners show differences in their navigational behaviour since:						
Only for global learners, going through conclusions is a significant behaviour pattern.	Conclusion	Conclusion			–0.35 (19.07*)	✓

Only for global learners, going through outlines is a significant behaviour pattern.	Outline	Outline	22.90* (20.54*)	×
Only for sequential learners, going step-by-step through the content is a significant behaviour pattern.	Content	Content	34.30* (68.85*)	×
Only for global learners, jumping from content to conclusions is a significant behaviour pattern.	Content	Conclusion	−1.24 (4.97*)	✓
Only for global learners, jumping from content back to outline is a significant behaviour pattern.	Content	Outline	−1.23 (10.24*)	✓
Only for sequential learners, returning to SA area after feedback is a significant behaviour pattern.	Content	SA test visited	8.66* (−1.89)	✓

Significant results on a level of 0.05 are indicated with an asterisk.

depending on their learning styles. Only three assumptions could not be confirmed because the investigated navigation patterns were found to be significant independent of the students' learning styles. For these three assumptions, further investigations are necessary in order to find out the students' intensions when applying the respective navigation patterns.

As outlined in the introduction, this study aimed at contributing towards the field of adaptive computer-assisted learning in three ways. First, this study aimed at showing that learners with different learning styles behave differently in a learning system with respect to their navigational patterns. As can be seen from our results, several differences were found. Therefore, these results provide another indication that learners with different learning styles use online courses in different ways and navigate through learning objects/activities differently, which can be seen as a basic requirement for providing adaptivity with respect to learning styles.

Second, from the results of this study, recommendations for providing adaptivity with respect to learning styles can be derived. Adaptive navigation support is one of the main technologies in adaptive learning systems (Brusilovsky 2001), showing the importance of investigating navigational behaviour for adaptive learning systems. Several systems exist in the literature, such as CS383 (Carver *et al*. 1999), TSAL (Tseng *et al*. 2008), and WELSA (Popescu 2008), which provide adaptivity based on navigational preferences with respect to learning styles. The adaptive features of these systems are based on the description of the learning style theory, which has been developed for learning in general rather than only for online learning. In this study, data were analysed from the navigational behaviour of students in a typical online course, providing conclusions about how students with different learning styles prefer to behave in an online environment. The results can be used to extend the functionality of adaptive learning systems, considering the preferred navigational behaviour of students with particular learning styles and recommending them a suitable way through the course or giving them suggestions about the next suitable learning object/activity if they need guidance.

Third, the resulting differences in navigational behaviour can contribute in student modeling. In the last few years, several research works have been conducted on developing an approach that identifies learning styles

automatically from students' behaviour in an online course (e.g. Cha *et al*. 2006; García *et al*. 2007; Graf *et al*. 2008). However, these approaches were mainly based on patterns, counting the students' visits of specific kinds of learning objects, how much time they spent on such learning objects and/or how they performed on exercises, tests or specific kinds of questions. This study shows that students with different learning styles also have different navigational behaviour. These differences can act as additional patterns in the automatic identification process of learning styles, allowing the usage of navigational behaviour as another source for getting information about students' preferred learning styles. Therefore, the results of this study can contribute in making the identification of learning styles more accurate and possible in shorter time.

Several studies in the literature have investigated students' behaviour in computer-assisted learning environments with respect to learning styles (e.g. Liegle & Janicki 2006; Lu *et al*. 2007; Graf & Kinshuk 2008). However, this study is different in several ways. First, the study aimed at investigating the behaviour of students in a typical online course. Therefore, the study was based on a course in a commonly used LMS rather than in a specific prototype system, and the course was composed of commonly used kinds of learning objects/activities. Second, while many other studies looked at behaviour in terms of how often and how long students visited specific kinds of learning objects/activities, this study has focused on the navigational behaviour, meaning how students went through the different kinds of learning objects/activities. However, the study has still focused on the context of the learning object/activity and investigated the sequence of kinds of learning objects/activities in which students go through the course rather than only looking at the navigational method, such as whether students use the next buttons or the menu for navigating through a course. Furthermore, this study is based on a learning style theory, commonly used in computer-assisted learning, making the findings more widely applicable.

A limitation of this study can be seen in the number of participants, resulting for some navigational patterns in a significant but low frequency that might need further investigations in order to be confirmed.

Future work will deal with incorporating the findings of this study in the automatic student modeling process of learning styles and evaluating its effectiveness in improving the accuracy of the detection process. Furthermore, future work will deal with using the knowledge about the different navigational preferences for providing adaptive and personalized navigation support. Moreover, investigations about students' navigational behaviour with respect to their performance and learning styles are planned, analysing which strategies help students with particular learning styles in learning and which strategies can have a negative impact on students' performance. Such findings can then be used to provide students with personalized suggestions and help them in choosing navigational strategies that have a positive effect on their learning performance. A potential example could be that once an active learner follows the feedback link at the results page of his/her SA test, an adaptive system can remind the student to go back after reading the feedback and looking at the results of the other questions rather than leaving the SA area. Furthermore, more detailed investigations will be conducted, analysing whether considering combinations of learning styles (such as learners who have an active and sensing learning style) can lead to further findings regarding learners' navigational behaviour.

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Appendix A

Tables A1, A2, and A3 present the results of the sequential analysis, showing the frequencies in which learners of the respective learning style dimensions go from one kind of learning object/activity to another. Frequencies which are significant on a level of 0.05 are indicated with an asterisk and written in bold font. Results regarding the investigated assumptions are indicated with a gray background.

Table A1. Frequencies of navigational behaviour of active and reflective learners.

	from to:	Others	Overview page	Forum	All-resources page	Outline	Content	Conclusion	Lecture notes	Example	All-quizzes page	SA test visited	SA test finished	Exercise visited	Exercise finished	All-assignments page	Assignment	Sum
Active learners (n = 40)	Others	**190***	**194***	**100***	18	2	11	1	20	27	0	17	0	7	0	2	21	610
	Overview Page	**156***	**938***	**537***	**211***	**115***	4	**20***	**341***	**257***	240	89	1	69	1	**312***	**410***	3701
	Forum	**97***	**548***	**1581***	4	1	3	0	1	2	6	3	1	0	0	6	29	2282
	All-Resources Page	23	157	4	32	5	**159***	**5***	**176***	**85***	2	3	2	1	0	4	40	698
	Outline	2	**108***	0	10	**35***	**23***	**4***	7	2	0	0	0	1	0	0	5	197
	Content	11	29	2	**147***	**20***	**303***	**6***	4	5	5	67	0	0	0	1	1	601
	Conclusion	1	**26***	0	**5***	**4***	1	0	0	1	1	0	0	0	0	0	0	39
	Lecture Notes	17	**355***	7	**146***	5	4	1	**167***	9	3	9	6	2	0	1	20	752
	Example	25	**259***	9	**72***	1	2	1	9	**239***	0	8	0	4	0	0	5	634
	All-Quizzes Page	1	121	7	2	0	1	0	2	0	20	**538***	6	**350***	2	1	3	1054
	SA test visited	17	137	7	1	0	4	0	6	5	**417***	250	**1366***	5	0	0	3	2218
	SA test finished	0	43	1	0	0	**81***	0	3	0	30	**1222***	9	1	1	0	1	1392
	Exercise visited	6	80	4	1	1	0	0	1	1	**264***	10	0	**193***	**270***	1	5	837
	Exercise finished	0	13	0	0	0	0	0	0	0	**60***	0	0	**201***	**17***	0	0	291
	All-Assignments Page	4	**210***	7	6	0	1	0	0	0	4	0	1	0	0	**24***	**256***	513
	Assignment	21	**509***	24	43	9	4	1	15	1	2	2	0	3	0	**164***	**336***	1134
	Sum	571	3727	2290	698	198	601	39	752	634	1054	2218	1392	837	291	516	1135	16 953
Reflective learners (n = 35)	Others	**297***	**252***	77	13	3	**77***	3	21	5	2	1	0	4	0	4	33	792
	Overview Page	**203***	896	618	**222***	**114***	4	**25***	**247***	**395***	**192***	122	5	97	2	**305***	**409***	3856
	Forum	91	622	**2008***	9	0	3	1	8	7	9	7	0	4	1	9	24	2803
	All-Resources Page	22	147	5	12	8	**176***	**7***	**119***	**143***	2	1	1	1	0	7	32	683
	Outline	10	**104***	1	10	**40***	**44***	**4***	4	4	0	2	2	2	0	0	2	229
	Content	**64***	42	8	**170***	**32***	**357***	5	3	7	5	**154***	8	2	1	0	2	860
	Conclusion	3	**28***	0	5	**3***	0	**8***	3	5	1	1	0	0	1	0	2	60
	Lecture Notes	18	**269***	15	**73***	11	2	3	**269***	15	2	2	1	0	1	0	31	712
	Example	6	**408***	11	**124***	5	6	2	6	**442***	1	14	1	10	3	1	12	1052
	All-Quizzes Page	2	109	10	4	0	1	0	0	0	21	**339***	0	**275***	0	3	2	766
	SA test visited	9	126	7	0	1	19	2	2	5	**266***	207	**1210***	9	0	0	5	1868
	SA test finished	0	31	6	3	0	**168***	0	0	3	20	**996***	15	2	0	0	0	1244
	Exercise visited	3	109	7	1	3	0	0	2	7	**209***	14	0	**182***	**249***	0	3	789
	Exercise finished	0	21	3	0	0	1	0	0	0	**30***	3	0	**199***	4	0	1	262
	All-Assignments Page	2	**227***	10	6	1	1	0	0	0	3	1	0	0	0	10	**208***	469
	Assignment	29	**481***	26	31	8	1	0	29	14	3	4	1	2	0	**135***	**323***	1087
	Sum	759	3872	2812	683	229	860	60	713	1052	766	1868	1244	789	262	474	1089	17 532

Table A2. Frequencies of navigational behaviour of sensing and intuitive learners.

	from to:	Others	Overview page	Forum	All-resources page	Outline	Content	Conclusion	Lecture notes	Example	All-quizzes page	SA test visited	SA test finished	Exercise visited	Exercise finished	All-assignments page	Assignment	Sum
Sensing learners ($n = 46$)	Others	**346***	**294***	134	18	2	**73***	2	25	30	0	18	0	5	0	2	34	983
	Overview Page	**228***	**1197***	816	**304***	**140***	5	**27***	**401***	**515***	**331***	159	4	120	3	**443***	**506***	5199
	Forum	147	830	**2749***	11	0	3	0	7	6	9	8	0	3	1	10	36	3820
	All-Resources Page	30	219	8	17	8	**218***	**9***	**202***	**173***	1	3	2	1	0	6	55	952
	Outline	7	**130***	1	12	**36***	**17***	**4***	7	2	0	0	1	3	0	0	3	223
	Content	**63***	48	6	**210***	11	**287***	4	4	8	7	**173***	5	1	0	0	1	828
	Conclusion	2	**28***	0	**8***	**3***	0	**6***	2	5	1	1	0	0	0	0	2	58
	Lecture Notes	20	**423***	8	**153***	10	3	4	**329***	19	3	9	7	0	0	0	32	1020
	Example	28	**534***	18	**149***	1	6	1	10	**441***	1	15	0	6	0	0	6	1216
	All-Quizzes Page	1	167	14	4	0	1	0	2	0	33	**657***	5	**517***	2	3	4	1410
	SA test visited	24	185	13	1	0	17	1	7	8	**507***	307	**1878***	8	0	0	5	2961
	SA test finished	0	59	6	2	0	**194***	0	3	1	45	**1589***	17	2	1	0	1	1920
	Exercise visited	5	140	8	1	2	0	0	1	2	**384***	14	0	**257***	**404***	1	3	1222
	Exercise finished	0	27	3	0	0	1	0	0	0	**81***	2	0	**296***	**16***	0	1	427
	All-Assignments Page	5	**308***	13	9	1	1	0	0	0	4	1	0	0	0	**30***	**335***	707
	Assignment	32	**636***	34	53	9	2	0	21	6	3	5	1	3	0	**217***	**454***	1476
	Sum	456	3534	1319	687	310	1128	58	590	743	708	2195	1428	754	252	368	1125	24 422
Intuitive learners ($n = 29$)	Others	**141***	**152***	43	13	3	15	2	16	2	2	0	0	6	0	4	20	419
	Overview Page	**131***	**637***	**339***	**129***	**89***	3	**18***	**187***	**137***	101	52	2	46	0	**174***	**313***	2358
	Forum	41	**340***	**840***	2	1	3	1	2	3	6	2	1	1	0	5	17	1265
	All-Resources Page	15	85	1	**27***	5	**117***	3	**93***	**55***	3	1	1	1	0	5	17	429
	Outline	5	**82***	0	8	**39***	**50***	**4***	4	4	0	2	1	0	0	0	4	203
	Content	12	23	4	**107***	**41***	**373***	**7***	3	4	3	48	3	1	1	1	2	633
	Conclusion	2	**26***	0	2	**4***	1	**2***	1	1	1	0	0	0	1	0	0	41
	Lecture Notes	15	**201***	14	**66***	6	3	0	**107***	5	2	2	0	2	1	1	19	444
	Example	3	**133***	2	**47***	5	2	2	5	**240***	0	7	1	8	3	1	11	470
	All-Quizzes Page	2	63	3	2	0	1	0	0	0	8	**220***	1	**108***	0	1	1	410
	SA test visited	2	78	1	0	1	6	1	1	2	**176***	**150***	**698***	6	0	0	3	1125
	SA test finished	0	15	1	1	0	55	0	0	2	5	**629***	7	1	0	0	0	716
	Exercise visited	4	49	3	1	2	0	0	2	6	**89***	10	0	**118***	**115***	0	5	404
	Exercise finished	0	7	0	0	0	0	0	0	0	9	1	0	**104***	**5***	0	0	126
	All-Assignments Page	1	**129***	4	3	0	1	0	0	0	3	0	1	0	0	4	**129***	275
	Assignment	18	**354***	16	21	8	3	1	23	9	2	1	0	2	0	**82***	**205***	745
	Sum	392	2374	1271	429	204	633	41	444	470	410	1125	716	404	126	278	746	10 063

Table A3. Frequencies of navigational behaviour of sequential and global learners.

	From to:	Others	Overview page	Forum	All-resources page	Outline	Content	Conclusion	Lecture notes	Example	All-quizzes page	SA test visited	SA test finished	Exercise visited	Exercise finished	All-assignments page	Assignment	Sum
Sequential learners ($n = 34$)	Others	**258***	**218***	61	17	1	**31***	0	13	8	0	0	0	8	0	2	27	644
	Overview Page	**171***	**939***	610	**216***	**120***	3	**29***	**369***	**395***	224	130	1	102	2	**303***	**369***	3983
	Forum	75	607	**2019***	11	0	4	0	7	6	9	5	1	3	1	13	32	2793
	All-Resources Page	25	155	7	32	4	**201***	**8***	**143***	**152***	2	2	1	1	0	5	30	768
	Outline	2	**117***	1	7	**33***	5	**4***	8	3	0	0	0	2	0	0	5	187
	Content	26	31	7	**193***	3	**162***	0	1	4	6	**146***	5	1	0	1	2	588
	Conclusion	0	**31***	0	**6***	**5***	0	0	1	2	1	0	0	0	0	0	1	47
	Lecture Notes	8	**386***	8	**115***	9	2	3	**226***	7	3	6	2	1	0	0	19	795
	Example	6	**396***	18	**134***	1	2	2	5	**320***	0	12	0	9	1	1	4	911
	All-Quizzes Page	0	119	8	1	0	0	0	1	0	26	**497***	5	**377***	2	2	0	1038
	SA test visited	8	146	7	0	0	16	0	1	5	**391***	293	**1537***	7	0	0	4	2415
	SA test finished	0	46	4	1	0	**159***	0	1	1	34	**1303***	18	2	1	0	1	1571
	Exercise visited	6	112	6	1	2	0	0	1	4	**278***	14	0	**225***	**311***	1	6	967
	Exercise finished	0	25	3	0	0	1	0	0	0	**59***	2	0	**227***	**14***	0	1	332
	All-Assignments Page	5	**233***	10	7	1	1	0	0	0	3	0	0	0	0	15	**217***	492
	Assignment	21	**442***	33	27	8	1	1	18	4	2	5	1	2	0	**152***	**311***	1028
	Sum	611	4003	2802	768	187	588	47	795	911	1038	2415	1571	967	332	495	1029	18 559
Global learners ($n = 41$)	Others	**229***	**228***	116	14	4	**57***	4	28	24	2	18	0	3	0	4	27	758
	Overview Page	**188***	**895***	545	**217***	**109***	5	16	**219***	**257***	**208***	81	5	64	1	**314***	**450***	3574
	Forum	113	**563***	**1570***	2	1	2	1	2	3	6	5	0	1	0	2	21	2292
	All-Resources Page	20	149	2	12	9	**134***	4	**152***	**76***	2	2	2	1	0	6	42	613
	Outline	10	**95***	0	13	**42***	**62***	**4***	3	3	0	2	2	1	0	0	2	239
	Content	49	40	3	**124***	**49***	**498***	**11***	6	8	4	75	3	1	1	0	1	873
	Conclusion	4	**23***	0	4	2	1	**8***	2	4	1	1	0	0	1	0	1	52
	Lecture Notes	27	**238***	14	**104***	7	4	1	**210***	17	2	5	5	1	1	1	32	669
	Example	25	**271***	2	**62***	5	6	1	10	**361***	1	10	1	5	2	0	13	775
	All-Quizzes Page	3	111	9	5	0	2	0	1	0	15	**380***	1	**248***	0	2	5	782
	SA test visited	18	117	7	1	1	7	2	7	5	**292***	164	**1039***	7	0	0	4	1671
	SA test finished	0	28	3	2	0	**90***	0	2	2	16	**915***	6	1	0	0	0	1065
	Exercise visited	3	77	5	1	2	0	0	2	4	**195***	10	0	**150***	**208***	0	2	659
	Exercise finished	0	9	0	0	0	0	0	0	0	**31***	1	0	**173***	**7***	0	0	221
	All-Assignments Page	1	**204***	7	5	0	1	0	0	0	4	1	1	0	0	19	**247***	490
	Assignment	29	**548***	17	47	9	4	0	26	11	3	1	0	3	0	**147***	**348***	1193
	Sum	719	3596	2300	613	240	873	52	670	775	782	1671	1065	659	221	495	1195	15 926

References

Alias N.A. & Zainuddin A.M. (2005) Innovation for better teaching and learning: adopting the learning management system. *Malaysian Online Journal of Instructional Technology* **2**, 27–40.

Bakeman R. & Gottman J.M. (1997) *Observing Interaction: An Introduction to Sequential Analysis*, 2nd edition. Cambridge University Press, Cambridge.

Blackboard (2008). Available at: http://www.blackboard.com (last accessed 27 September 2008).

Briggs Myers I. (1962) *Manual: The Myers-Briggs Type Indicator*. Consulting Psychologists Press, Palo Alto, CA.

Brusilovsky P. (2001) Adaptive hypermedia. *User Modeling and User-Adapted Interaction* **11**, 87–110.

Carver C.A., Howard R.A. & Lane W.D. (1999) Addressing different learning styles through course hypermedia. *IEEE Transactions on Education* **42**, 33–38.

Cha H.J., Kim Y.S., Park S.H., Yoon T.B., Jung Y.M. & Lee J.-H. (2006) Learning style diagnosis based on user interface behavior for the customization of learning interfaces in an intelligent tutoring system. In *Proceedings of the International Conference on Intelligent Tutoring Systems, Lecture Notes in Computer Science*, Vol. 4053 (eds M. Ikeda, K.D. Ashley & T.-W. Chan), pp. 513–524. Springer, Berlin, Heidelberg.

Coffield F., Moseley D., Hall E. & Ecclestone K. (2004) *Should We be Using Learning Styles? – What Research Has to Say to Practice*. Learning and Skills Research Centre/ University of Newcastle upon Tyne, London.

Cristea A. & Stash N. (2006) AWELS: adaptive Web-based education and learning styles. In *Proceedings of the International Conference on Advanced Learning Technologies* (eds Kinshuk, R. Koper, P. Kommers, P. Kirschner, D. Sampson & W. Didderen), pp. 1135–1136. IEEE Computer Science, Los Alamitos.

Felder R.M. & Silverman L.K. (1988) Learning and teaching styles in engineering education. *Engineering Education* **78**, 674–681.

Felder R.M. & Soloman B.A. (1997) Index of Learning Styles Questionnaire. Available at: http://www.engr.ncsu.edu/learningstyles/ilsweb.html (last accessed 15 January 2009).

Felder R.M. & Spurlin J. (2005) Applications, reliability and validity of the Index of Learning Styles. *International Journal of Engineering Education* **21**, 103–112.

García P., Amandi A., Schiaffino S. & Campo M. (2007) Evaluating Bayesian networks' precision for detecting students' learning styles. *Computers & Education* **49**, 794–808.

Graf S. & Kinshuk (2007) Providing adaptive courses in learning management systems with respect to learning styles. In *Proceedings of the World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education (e-Learn)* (ed. G. Richards), pp. 2576–2583. AACE Press, Chesapeake, VA.

Graf, S. & Kinshuk (2008) Analysing the behaviour of students in learning management systems with respect to learning styles. In *Advanced in Semantic Media Adaptation and Personalization, Series on Studies in Computational Intelligence*, Vol. 93 (eds M. Wallace, M. Angelides & P. Mylonas), pp. 53–74. Springer, Berlin/Heidelberg.

Graf S., Kinshuk & Liu T.-C. (2008) Identifying learning styles in learning management systems by using indications from students' behaviour. In *Proceedings of the International Conference on Advanced Learning Technologies* (eds P. Diaz, Kinshuk, I. Aedo & E. Mora), pp. 482–486. IEEE Computer Science, Los Alamitos.

Honey P. & Mumford A. (1982) *The Manual of Learning Styles*. Peter Honey, Maidenhead.

Hou H.-T., Chang K.-E. & Sung Y.-T. (2008) Analysis of problem-solving-based online asynchronous discussion pattern. *Educational Technology & Society* **11**, 17–28.

Jonassen D.H. & Grabowski B.L. (1993) *Handbook of Individual Differences, Learning, and Instruction*. Lawrence Erlbaum Associates, Hillsdale, NJ.

Kolb D.A. (1984) *Experiential Learning: Experience as the Source of Learning and Development*. Prentice-Hall, Englewood Cliffs, NJ.

Kuljis J. & Liu F. (2005) A comparison of learning style theories on the suitability for elearning. In *Proceedings of the IASTED Conference on Web Technologies, Applications, and Services* (ed. M.H. Hamza), pp. 191–197. ACTA Press, Calgary, AB.

Liegle J.O. & Janicki T.N. (2006) The effect of learning styles on the navigation needs of Web-based learners. *Computers in Human Behavior* **22**, 885–898.

Livesay G.A., Dee K.C., Nauman E.A. & Hites L.S. (2002) Engineering student learning styles: a statistical analysis using Felder's Index of Learning Styles. Presented at the *Annual Conference of the American Society for Engineering Education* (June 2002), Montreal, Canada.

Lu H., Jia L., Gong S.-H. & Clark B. (2007) The relationship of Kolb Learning Styles, online learning behaviors and learning outcomes. *Journal of Educational Technology & Society* **10**, 187–196.

Moodle (2008) Available at: http://www.moodle.org (last accessed 27 September 2008).

Moodle Sites (2008) Available at: http://moodle.org/sites/ (last accessed 5 October 2008).

Pask G. (1976) Styles and strategies of learning. *British Journal of Educational Psychology* **46**, 128–148.

Popescu E. (2008) *Dynamic adaptive hypermedia systems for e-learning*. PhD Thesis, Université de Craiova, Romania.

Sakai (2008) Available at: http://www.sakaiproject.org/portal (last accessed 27 September 2008).

Sung Y.-T., Chang K.-E., Lee Y.-H. & Yu W.-C. (2008) Effects of a mobile electronic guidebook on visitors' attention and visiting behaviors. *Educational Technology & Society* **11**, 67–80.

Tseng J.C.R., Chu H.C., Hwang G.J. & Tsai C.C. (2008) Development of an adaptive learning system with two sources of personalization information. *Computers & Education* **51**, 776–786.

Van Zwanenberg N., Wilkinson L.J. & Anderson A. (2000) Felder and Silverman's Index of Learning Styles and Honey and Mumford's Learning Styles Questionnaire: how do they compare and do they predict academic performance? *Educational Psychology* **20**, 365–380.

Zywno M.S. (2003) A contribution to validation of score meaning for Felder–Soloman's Index of Learning Styles. Presented at the *Annual Conference of the American Society for Engineering Education* (June 2003), Nashville, USA.