

Visualising Student Tracking Data to Support Instructors in Web-Based Distance Education

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ABSTRACT

This paper presents a novel approach of using web log data generated by course management systems (CMS) to help instructors become aware of what is happening in distance learning classes. Specifically, techniques from Information Visualization are used to graphically render complex, multidimensional student tracking data collected by CMS. A system, called CourseVis, illustrates the proposed approach. Graphical representations from the use of CourseVis to visualise data from a java on-line distance course ran with WebCT are presented. Findings from the evaluation of CourseVis are presented, and it is argued that CourseVis can help teachers become aware of some social, behavioural, and cognitive aspects related to distance learners. Using graphical representations of student tracking data, instructors can identify tendencies in their classes, or quickly discover individuals that need special attention.

Categories and Subject Descriptors

K.3.1 [Computer Uses in Education]: Distance learning

General Terms

Management, Human Factors, Verification

Keywords

Web-based distance education, student tracking, information visualization

1. INTRODUCTION

The World Wide Web provides great opportunities for creating virtual classrooms of learners and instructors involved in distance education. Many software environments take advantage of the client-server communication on the Internet and support open and distance learning [1]. Using environments called Course Management Systems (CMS), instructors can distribute information to students, produce content material, prepare assignments and tests, engage in discussions, and manage distance classes [19]. CMS have been widely used nowadays for their great potential to enable interactive web-based teaching and to support the administration of distance courses. Because CMS are popular, their effectiveness is very important and has been extensively studied. A number of problems with using CMS in distance learning have been reported, e.g. students may feel

isolated due to lack of contact with the instructor or with other students, can get disorientated in the course hyperspace, may lose their motivation, and often find it difficult to manage without institutional support (including help with technical problems) [25][8][24][30][10]. The drop-out rates of Web-based courses are in general higher than those in regular classes [25].

The effective use of CMS in distance education requires that instructors should be provided with appropriate means to diagnose that a problem might arise or has arisen, so that they can take immediate actions to prevent or overcome that problem. An approach to support instructors in online distance education using data from web log mining is described in this paper. Specifically, we employ Information Visualization techniques to produce various graphical representations from student tracking data collected by CMS, and thus to help teachers gain an understanding of what is happening in their classes. A system, called CourseVis [16] [18], has been developed to extend an existing commercial CMS, namely WebCT. The evaluation of CourseVis [18] has shown that it can help teachers become aware of some social, behavioural, and cognitive aspects related to distance learners. Using graphical representations of student tracking data, instructors can identify tendencies in their classes, or quickly discover individuals that need special attention.

Next in the paper, in Section 2, we will discuss related work that justifies the use of web log mining for dealing with problems in distance courses maintained with CMS. In addition, recent projects that employ visualization techniques in web based teaching will be outlined to place our work within the relevant literature. Section 3 will briefly describe the CourseVis system focusing on the visualization approach used. The three aspects of students considered in CourseVis – social, behavioural, and cognitive – will be illustrated with the help of examples in Sections 4, 5, and 6, respectively. Section 7 will sketch out some of the findings of the CourseVis evaluation. In the concluding Section 8 we will point at advantages of the approach presented here and will outline some plans for future work.

2. STUDENT TRACKING AND DATA VISUALIZATION

Educational research shows that monitoring the students' learning is an essential component of high quality education, and is "one of the major factors differentiating effective schools and teachers from ineffective ones" [6]. This applies also to online teaching, e.g Helic et al. [12] argue that a good online tutoring requires monitoring of a learner's progress with the material and testing of the acquired knowledge and skills on a regular basis. Assessment and measurement enables teachers to gauge the student response,

feedback, and progress towards goals, and is crucial in distance education [22] where “the learner is impaired by the lack of casual contact with the teacher and other students” [8].

CMS accumulate large log data of the students’ activities in a distance course and usually have built-in student monitoring features that enable the instructor to view some statistical data, such as a student’s first and last login, the history of pages visited, the number of messages the student has read and posted in discussions, marks achieved in quizzes and assignments, etc. Instructors may use this information to monitor students’ progress and to identify potential problems. However, tracking data is usually provided in a tabular format, is often incomprehensible, with a poor logical organisation, and is difficult to follow. As a result, web log data is used only by skilled and technically powerful distance learning instructors. Moreover, CMS do not provide information about the actual learning that is taking place (e.g. the level of understanding achieved by a student on a particular concept, some indication of which concepts from the course material the students face difficulties with, etc.), albeit such information is very important for instructors in distance learning [17]. Recently, some proposal on extending web-based tutoring systems to keep the instructor informed about the progress and the problems encountered by the class has been proposed, such as the Logic-ITA [20].

A novel approach is proposed here whereby Information Visualization (IV) techniques [5][26][28] are adopted to graphically render a vast amount of student tracking data collected by CMS. Using sophisticated IV tools, instructors can manipulate the graphical representations generated, which will help instructors gain an understanding of their learners and become aware of what is happening in distance classes.

Some forms of visualizing cognitive aspects of students have been explored in open student models. For instance, ViSMod [33] uses concept maps to render a Bayesian student model, UM [14] exploits different types of geometric forms to represent known/unknown concepts, and KERMIT [11] uses histograms to represent levels of a student’s knowledge. The pictorial representations used in open student models externalise a student model built by the system based on some Artificial Intelligence inference. Extracting student and group models can be fairly challenging, especially when large numbers of students are dealt with. By contrasts, Information Visualization techniques merely represent data collected by CMS in a visual format with minimum data processing. By managing students’ tracking data with appropriate visualization techniques instructors form mental models [26] of individual students as well as mental models of groups of students. In this case models are inferred in the instructor’s mind, instead of being inferred by algorithms.

Visualization techniques have been used to visualise social aspects in computer-supported collaborative learning [23], community relationships in peer-to-peer systems [4], and conversations in online groups [7]. These projects commonly explore only one graphical representation to solely present data in a pictorial way and provide no operations to manipulate the graphics. Contrarily, not only does CourseVis employ several graphical representations to show social aspects but it also provides a rich set of IV operations to manipulate the graphics, such as zooming, filtering, rotating.

Recently, tools for visualising user models are being developed, e.g. [29]. These projects explore some visualization techniques to

show specific perspectives of the data. While we also explore some of these techniques (e.g. colour, shape, size), CourseVis provides multiple representations of the same set of data to show different perspectives. Furthermore, whilst user model visualisers built their own renders which are suited for the specific user model format considered, we explore a powerful, generic IV tool (OpenDX [20]). This has enabled us to quickly adapt CourseVis to distance learning courses and to deploy it in realistic settings in order to evaluate the usefulness, effectiveness, and efficiency of the graphics.

3. THE COURSEVIS

CourseVis is a visualization tool that obtains tracking data from a CMS (WebCT [32] is used in the current exemplification of CourseVis), transforms the data into a form convenient for processing, and generates graphical representations that can be explored and manipulated by course instructors to examine social, cognitive, and behavioural aspects of distance students.

3.1 Design guidelines

The design of CourseVis was based on the following guidelines:

1. **Users driven design.** A survey [17] with instructors involved in distance learning was conducted to find out what information about distance students the instructors needed when they ran courses with CMS, as well as to identify possible ways to help instructors acquire this information.
2. **Easy to use.** Many instructors have serious difficulties using CMS (even the basic functionality). The usability of a learning system is of a paramount importance. CourseVis is designed to support instructors with limited technical skills.
3. **Integration within existing CMS.** CMS are widely used in distance learning courses, and CourseVis was built in conjunction with a commercial web based CMS. Hence, the instructor does not need to learn another system.
4. **Domain independence.** Domain independence is critical for reuse of technology. Moreover, the integration with a commercial CMS required some independence from domain to be enrolled in CourseVis.
5. **CMS independence.** The implementation of CourseVis is not restricted to a specific course management system. Despite differences in the format of the tracking information provided by various CMS, there are commonalities in the content and the structure, e.g. history of pages visited, marks students receive for each quiz, messages posted to discussion forums, etc. This justified the design of CourseVis as a generic course visualization tool that could be applied to a wide range of distance learning environments.
6. **Free open source development.** The free open source software initiative is becoming widely supported ([<http://www.gnu.org>]; [<http://www.opensource.org>]). The basic idea is that the software must be free to read, modify, improve, reuse, and redistribute. This idea is followed in CourseVis, implemented using only open source software.

3.2 Data processing and visualization procedure in CourseVis

CourseVis includes a *Student Data Exporter* that collects and transforms the student tracking data provided from the CMS in a well-defined XML format. A specific implementation of the

Student Data Exporter for the WebCT course management system was built. The XML data produced by the Student Data Exporter is stored in a *Raw Data Repository*. A *Domain Designer* is a module dedicated to instructors to define the domain model of the course. The domain model describes the entities of the course domain (i.e. the course concepts) and their relationships with the pages of the course and questions in quizzes. A *Domain Model Repository* stores the XML data produced by the Domain Designer. The architecture of CourseVis is discussed in [16].

To represent data in visual format we need to do some computations and transform the data into visual structures and representations. This step is performed in CourseVis by the *Data Processing Procedure*, which follows the “visualization pipeline” model proposed by Stuart Card et al.[5], see Figure 1.

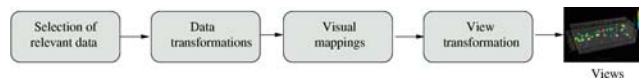


Figure 1: Visualization pipeline followed in CourseVis, derived from the reference model for visualization proposed by S. Card.

Data stored in the repositories is passed through a pipeline of four stages:

(a) *Selection of relevant input data*. Repositories contain a vast quantity of students’ data. Depending on the representation we want to produce, this stage extracts from the repositories only data relevant to the particular representation.

(b) *Data transformation*. This step manipulates the selected data extracted from the repository and generates an intermediate format which may add further metadata of the abstract representation. Data provided by the CMS and stored into the repositories often need to be transformed to add additional information (for instance the data contain errors or missing values that must be addressed before the data can be visualised), or to perform some calculations (such as statistical calculations to add additional information).

(c) *Visualization mapping*. This step transforms the pre-processed filtered data into geometrical primitives with appropriate attributes able to be processed by the human vision, such as colour or opacity. Visualization mapping is the core of the visualization process.

(d) *View transformation*. This step generates the image by using the geometric primitives from the mapping process by specifying graphical parameters such as position and scale. These graphical parameters are controlled by the user interaction, to perform some graphical manipulation such as zooming, scaling, panning etc.

In CourseVis, the first two steps from the pipeline are implemented with modules written in Perl while the last two stages are implemented within the visualization tool used, i.e. OpenDX [20].

3.3 Model of the graphics design in CourseVis

To implement graphical representations in CourseVis, we have followed the design space model proposed by Card et al. in [5]. This model aims to describe the mapping of abstract data (data which has no correspondence in a physical space, such as students’ names) in a spatial mapping. According to this model, raw data (**D**) may come in many forms and can be classified in three basic types: **N** (normal, unordered set, e.g. list of names); **O**

(ordinal, an ordered set that obeys the “<” relation, e.g. dates); **Q** (quantitative, numeric values that can be manipulated arithmetically). The visual mapping of the visualization process (see the reference model in Figure 1) transforms abstract data in visual structures with marks and graphical properties to encode information. Visual structures consist of:

- Marks: (**P** – point, **L** – line, **A** – area, **V** – volume)
- Automatically processed graphical properties
 - Positions: **X, Y, Z** (spatial coordinates)
T (to encode temporal information)
 - Retinal encodings: **C** – colour
S – size

In the following three sections we illustrate pictorial representations generated in CourseVis. The data used is from an on-line course in Java Programming run by the first author at the Department of Informatics and Electronics of the University of Applied Sciences of Southern Switzerland.

4. VISUALISING SOCIAL ASPECTS OF LEARNERS

The preliminary survey performed with instructors involved in distance learning indicated that representations of students’ social activities in the course should consider the data provided by the communication facilities included in that course, i.e. the discussions board. The discussion board is a tool which allows students to exchange (read and post) messages. Each message has a sender, a date, and a topic. The length of a thread (i.e. the number of messages written on a specific subject) is called follow-up and is sometimes useful for monitoring group work. We want to create a graphical representation that illustrates for each thread the student who started the thread, i.e. the “*originator*”, along with the *date* the thread was created, the *topic* where the thread is located, and the *follow-up* received. These are the three variables to consider in the representation.

One representation used in CourseVis to represent social aspects in *discussion plot* in which the discussion board variables (originator, date, time) are mapped onto the three dimensions of a 3-D scatterplot, as illustrated in the table below. An additional dimension – the size of the discussions – is represented by using different size: the size of the spheres represents the number of follow-ups in a discussion.

Variable	D	X	Y	Z	T	R
Originator	N	P				
Date	O		P			
Topic	N			P		
Follow-up	Q					S

The instructor may use operations, such as rotating and zooming, to manipulate the image.

Figure 2 and 3 show two rotations that enable the analysis of different relations by examining the same data set. The first one presents the discussion threads open by each student during the course, while the second one presents the discussed topics. Certain social characteristics of students can be discovered. For

instance, it can be seen that the discussions were predominantly initiated by students, and two individuals (Francesco and Massimo) dominated in opening threads followed up by others. The figure also identifies students who have not been active in opening discussions. The instructor may need to pay more attention at these students.

CourseVis uses another representation for social aspects - *discussion graph* - which maps two variables (number of threads started and number of postings by student) onto the dimensions of a 2D diagram using an x-axis composition [18].

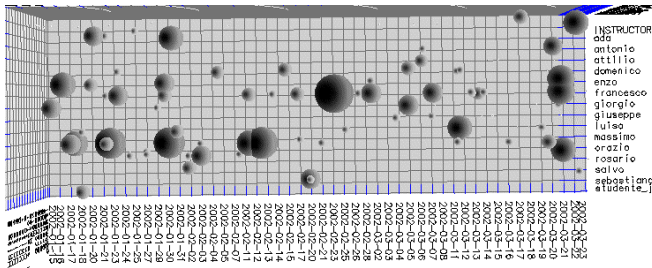


Figure 2: Visualization of discussion threads focusing on the students who have initiated the threads

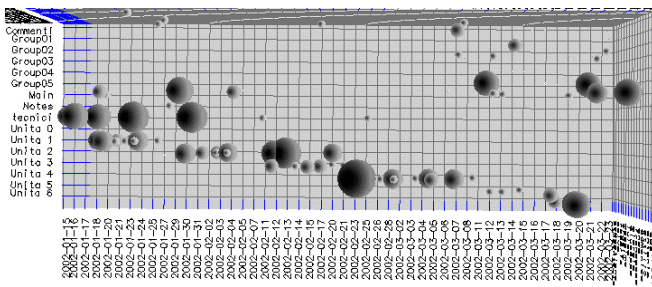


Figure 3: Visualization of the discussions related to the course units and group activities

5. VISUALISING COGNITIVE ASPECTS OF LEARNERS

The survey with instructors indicated that representations of students' cognitive level should consider for each student the overall performance in the course and in specific concepts of the domain. Representation should highlight students having difficulties with a concept and enable comparison of a student's progress with that of the whole class.

For the cognitive aspects of learners, CourseVis produced two graphical representation - *cognitive matrix* (see Figure 4) and *cognitive plot*.

The variables to consider in a graphical representation of cognitive aspects and their mapping are given in the following table:

Variable	D	X	Y	Z	T	R
Student	N	P				
Concept	N		P			
Performance	Q					C

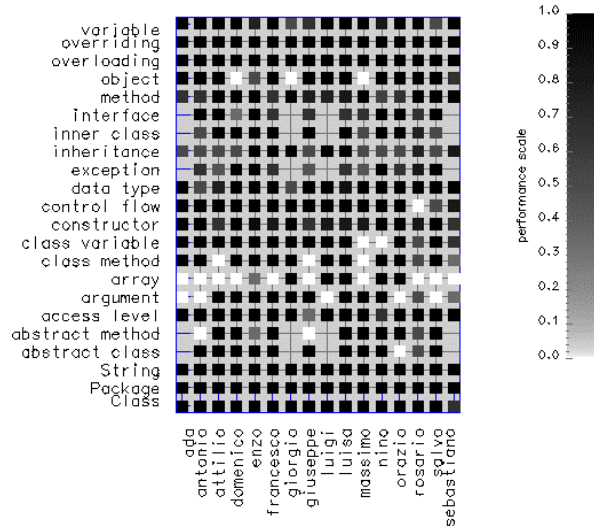


Figure 4: A matrix for visualizing the student's performance on quizzes related to domain

A cognitive matrix uses the students' performance on quizzes to assess the students' understanding of the subject. The students are mapped onto the x-axis and the concepts are mapped onto the y-axis of the matrix. The performance values are mapped onto the colour of the mark corresponding to a student and a concept, which is represented with a square. If a student has not attempted to answer questions related to a concept, the corresponding cell is left blank.

The matrix enables global analysis of the overall performance of students on the course topics and comparison between topics. This can promote the instructor's reflection on his practice. For instance, surprisingly, array was found a difficult concept by most of the students, and looking at the course material, the instructor found some vague presentations and quizzes that had to be improved. The matrix also allows local analysis of the performance of a particular student on a specific topic and comparison between students. For example, it can be identified that even though Massimo was successful in opening long discussion threads, while his performance at quizzes was not excellent. Such a student could be encouraged to pay more attention at reading course material.

6. VISUALISING BEHAVIOURAL ASPECTS OF LEARNERS

Survey analysis indicated that representations of students' behaviour should consider the students' attendance to the course, the reading of materials, the performing of evaluation proofs, the participation in discussions, and finally the students' progressing with the schedule of the course.

For the behavioural aspects of learners, several graphical representations were produced. They were shown separately but also in one representation as *behaviour graph*, illustrated in Figure 5. It represents information regarding a particular student, and takes advantage of single-axis composition method [15] for presenting large number of variables in a 2D metric space. With a common x-axis mapping the dates of the course, a number of variables are represented:

Summary of student's behaviours

from 2002-01-15 to 2002-04-11

Student: "francesco"

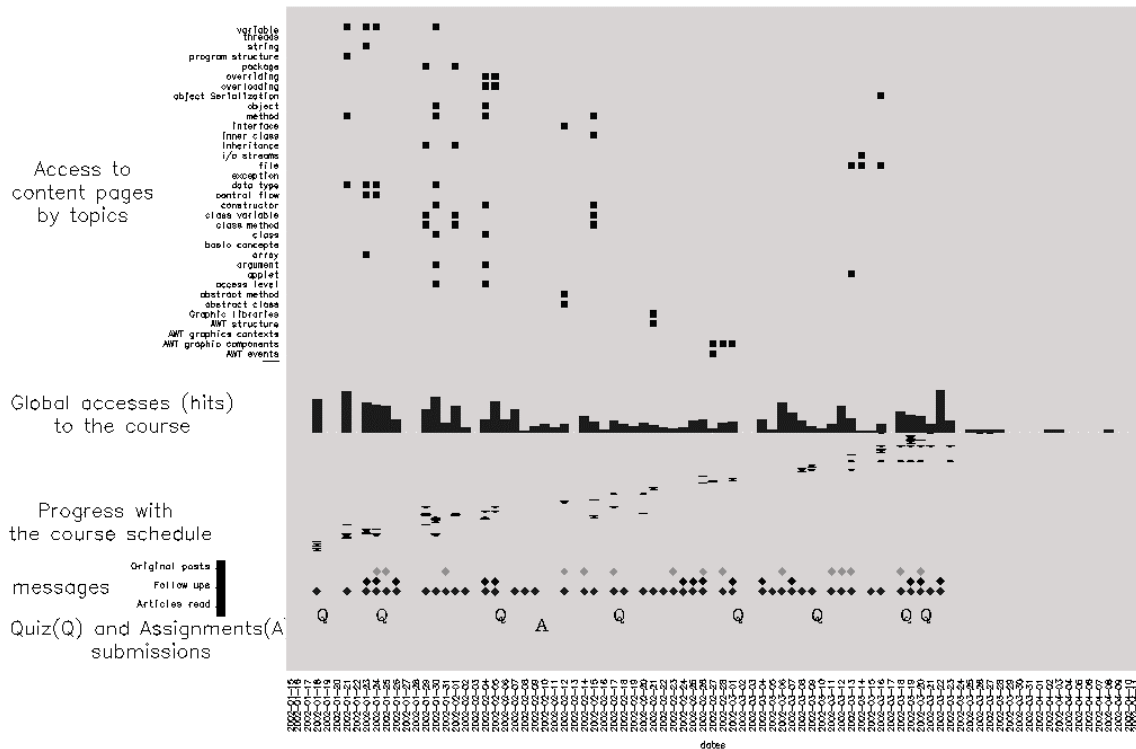


Figure 5: Representation of the students' behaviour

- *Accesses to content pages by topics.* If a student accessed a content page of materials dealing with a particular concept, it is marked with a square. The instructor can see the concepts studied by the student, or if the student repeatedly accesses particular concepts.
- *Global accesses to the course.* The number of accesses to the course (not only content materials, but to any part of the course) on a single day are computed and this value is reported on the histogram. The length of the bar of the histogram on each day is proportional to this number. The instructor can detect days or periods with high activities or times when the students have not accessed the course.
- *Progress with the course schedule.* We assume that the course has a linear structure, i.e. it has a syllabus with a list of content pages having a schedule organised in a linear sequence (the table of contents). We put in the y-axis the page ordering according to this sequence, a mark then represents a page accessed by the student on a day, where the y-location of the mark is proportional to the sequence of the pages in the schedule (first page on bottom, last page on top). The instructor may have an overview of the progress made by the student with the schedule during the time, which is useful to determine the learning style of the student (e.g. a student who reads, or prints lots of pages at once and then doesn't read anything for a while, versus a student who

follows a more consistent and progressive reading of the material). The representation in the example in Figure 5 shows that the student Francesco was particularly constant and methodical in reading the course materials following the schedule of the course. However, there were students in that Java on-line course who were not very constant, and never accessed some parts of the course material.

- *Messages.* Some information about the participation in discussion has been already considered in the discussion plot. However, some further information on discussion attendance could be given. In particular information about the posting of a new message, the reply to a message, or simply the reading of a message are denoted in the representation with a diamond coloured in a different colour (e.g. red, green and blue). Instructor may use this information to determine if a student is particularly proactive, if he read messages regularly (like the student Francesco in the example showed), or if he didn't read messages at all.
- *Quiz and assignment submission.* The submission of a quiz or an assignment is reported in the graphic on the date it was submitted with a Q or A. The instructor may use this information to assess the students' progress with assessed work.

The variables used in the behaviour graph shown in Figure 5, and their mapping, are given in the following table:

Variable	D	X	Y	Z	T	R
Date	O	P				
Global accesses	Q		P			
Concepts	N		P			
Hits	Q		P			
Content pages	O		P			
Messages			P			C
Quiz submission			P			
Assignment submission			P			

7. EVALUATION WITH INSTRUCTORS

An empirical evaluation of CourseVis was conducted focusing on its effectiveness (can it help instructors gain an understanding of what is happening in distance classes), efficiency (can instructors infer required information quickly), and usefulness (to what extent the information provided is useful to the instructors). The evaluation involved instructors with experience in using CMS in distance learning, and took place in three stages.

- A *focus group* was conducted with five instructors from Leeds University who were presented with CourseVis. The aim was to identify problems with the representations generated in CourseVis and assess their usefulness.
- An improved version of the system was then used in an *experimental study* involving six instructors with experience in distance learning from the University of Lugano and the University of Applied Sciences of Southern Switzerland. Data from a previously run distance course on Java programming was used. Instructors were asked to imagine that they were running the course (all participants had a good understanding of the domain and of the CMS used) and had to find some information about the students in order to answer a set of pre-designed questions, e.g. which are the struggling students, who are the most communicative students, etc. Three instructors used a course management system – WebCT - without CourseVis and three used WebCT with CourseVis. Dependent variables were accuracy of the answers, time taken to answer, and tools used.
- Finally, *semi-structured interviews* were conducted with the three participants who used CourseVis in the experimental study to discuss the usefulness of the graphical representations.

Due to the scope of this paper, only a brief summary of the evaluation results is provided below, the CourseVis evaluation is presented in detail in [18].

Generally, there was a positive feedback about the representations generated in CourseVis and the instructors would like to use the system in their distance courses. The most appreciated feature

was the "*immediacy*" – CourseVis provided quickly a lot of information that would normally require too much time and effort for the teachers to find when using the CMS standard tools. It became apparent that not only could CourseVis provide information more quickly, but it also significantly extended the scope of the understanding that the instructors could gain about distance students. Some information, e.g. the students' progression with domain concepts, was not possible to gather within a reasonable time with the tools provided in WebCT. It took longer to identify individual cases or to discover tendencies when only the WebCT student monitoring facilities were used. The accuracy of the information gained was notably higher when graphical representations from CourseVis were used.

Many of the graphical representations generated in CourseVis were regarded as useful but there were some problems identified and suggestions for further improvement pointed out.

- **Social aspects** (discussion plot and discussion graph, see Section 4). These representations enabled instructors to gain some understanding of what was happening in discussion forums that was considered highly important for interactive web-based instruction and may help to diagnose/overcome problems, such as the lack of communication and the feeling of isolation. However, it was found that the rotation of the discussion plot was confusing and it was mainly used when rotated in a way that only 2 dimensions could be examined (as it has been done in Figures 2 and 3). Instructors pointed out that more representations were needed to monitor how often a student has posted messages, who is attending discussions vicariously, etc. Some instructors pointed out that a direct link between the graphical representations and the interaction trends from the discussion forum would be very beneficial.
- **Cognitive aspects** (cognitive matrix and cognitive graph, see Section 5). Predominantly, these representations received a very positive feedback. The instructors could monitor how the students had progressed with the material, identify individuals who may need attention, compare students' performance, identify problems with the content material and concepts that may need further elaboration. Some instructors pointed out that it would be very helpful to have a link from the cognitive matrix to representations about social and behavioural aspects, so they can investigate reasons for students struggling with concepts (e.g. not reading the course material or not participating in discussions).
- **Behavioural aspects** (access plot and behaviour graph, see Section 6). The participants regarded the information provided by these representations as useful to monitor course attendance, identify drop-outs at an early stage, judge the students' commitment to the course, assess the frequency of visiting course material, etc. Although the combination of several techniques to give different perspectives of data in one graphical representation was considered helpful, most instructors felt that the behaviour graph (see Figure 5) provided much more than what was needed, and was difficult to absorb. Enabling instructors to select which data should be presented was recommended for a further improvement of CourseVis.

An additional benefit from the use of the graphical representations is that instructors may be encouraged to reflect on the way they prepare materials and run their courses. As one of the participants pointed out “These graphics help you think”. Instructors could quickly identify what might be going wrongly and investigate reasons (e.g. lack of group interactions when group tasks have been inappropriate; problems with specific concepts due to insufficient or inadequate materials provided; students’ failure at quizzes due to vague questions, etc).

8. CONCLUSIONS AND FUTURE WORK

This paper presents a novel approach of using web log data generated by course management systems to help instructors become aware of what is happening in distance learning classes. Specifically, techniques from information visualization have been used to graphically render complex, multidimensional student tracking data collected by CMS. A system, called CourseVis, illustrates the proposed approach. CourseVis has been developed as a generic tool for visualising student tracking data – it is required that the data from CMS are converted into an xml format, which is then imported into the CourseVis graphical render to produce various representations of the data. An instantiation of CourseVis to extend the functionality WebCT, a widely used commercial CMS, has been developed. Some representations from this CourseVis instantiation are presented in the paper to illustrate the use of information visualization for rendering student tracking data.

The evaluation of CourseVis has shown that the representations help instructors to quickly and more accurately grasp information about social, cognitive, and behavioural aspects of students. The provided information was regarded by the teacher as very useful for managing successful distance courses. It was noted that the graphical representations provided in CourseVis may help instructors identify early, and even prevent, some of the problems with distance learning, e.g. students who do not communicate might feel isolated, a student not visiting the course material might be confused or be a potential drop-out, long discussion threads on a topic may highlight problems experienced by learners (e.g. technical aspects).

CourseVis has been regarded as a very useful tool by the participants in the evaluative studies we have conducted, and further improvement has been suggested. This includes providing flexible links between the graphical representations, ensuring a connection between graphics and corresponding data from CMS (e.g. a link from a discussion graph to postings in the discussion forum), enabling instructors to say what data should be included or excluded from graphics. The next version of CourseVis will address these aspects and will be implemented within the framework of the recently started EU funded EdukaLibre project. The project will examine the use of free, open source to develop a truly free and open learning environment that will not only mimic commercial CMS but will also further extend the CMS functionality, for example, with visualization tools that have been demonstrated in this paper.

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