Computer-supported Formation of Virtual Learning Groups based on Proficiency Levels

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Abstract: Group work is an important component of traditional teaching at all levels of the educational system: It is motivating, the students become active and involved, they enjoy meeting with other students and doing work together. Based on the principle of social constructivism, role-based learning is an especially powerful paradigm for group work. But in a networked virtual environment, the organization of such group work can be very complex and time-consuming. In this paper we briefly introduce CATS, our Communication and Tutoring System. We then focus on its built-in support for the automatic formation of virtual learning groups, as well as on the seamless integration of audio/videoconferencing. We give a detailed example borrowed from the law school curriculum: “moot court”, a simulated mock court hearing where the students play the roles of prosecutor, defender and judge over the network.

1 Introduction

Pedagogical psychology distinguishes between four major learning theories: Behaviorism is based on the principle of drill and practice (Pawlow, 1953), (Skinner, 1974). The learning process is based entirely on external stimuli, on particular incentives and punishments. The behaviorist principle is used in many computer-based trainings (CBTs). The motivation for the students is extrinsic.

Cognitivism recognizes the learner as an individual who is able to interpret external stimuli and can control the learning process (Piaget 1977), (Brunner 1966). CBTs and cooperative learning tools based on cognitivism have to be adaptive to the internal conditions of the learner (experience, proficiency, etc.).

The theory of constructivism believes that the learner constructs his/her reality based on his/her individual know-how and experience (Maturana et. al. 1987). In constructivism individual knowledge is not an image of the external reality; it is a function of cognitive processes.

A further step in line with that theory is social constructivism: New knowledge is constructed in knowledge communities since knowledge is historical and changeable, exercises and tutorials in small groups are an important component of learning at all levels of education. It is now generally believed that communication with peers and with the tutor in small group settings is very helpful in the acquisition and internalization of knowledge (Bransford et. al. 2000), (Qin et. al., 1995), (Slavin, 1980).

But what do we find if we look at today’s distance-learning scenarios? The state-of-the-art is online retrieval of exercises/problems from the teacher's Web server, followed by individual work on those problems, and submission of the solution, either on paper or electronically to the server or by email, for manual evaluation by the teacher. These are several drawbacks to such exercise systems:

- Lack of group activity.
- Same exercises for all students regardless of individual knowledge or learning style.
- Time consuming manual grading by the instructor of each individual submission.
- Lack of immediate, individual helps for the student in the face of difficulties with particular exercises. This constitutes a considerable drawback as opposed to a traditional face-to-face scenario.

CATS, the communication and tutoring system under development at the University of Mannheim, attempts to provide solutions to these issues (Liebig et al., 2003). The basis on all our algorithms is a continuous measurement of the performance of the individual learner. We use the measurement results in different ways and phases: First we adapt the exercise problems to the respective proficiency level, then we create virtual learning groups to solve a given problem, and we integrate seamless communication with a videoconferencing facility.
Our key idea is to automatically create online groups of learners, teams that are able to solve a group assignment at a given level of proficiency.

Related Work

Related work in the literature has addressed some but not all of these issues, and not in an integrated fashion. Early work on automated computer-supported exercises began in the 1950s with the first simple training systems. A much more advanced integration with artificial intelligence and a tutoring concept with a domain, student and tutor model respectively is the basis of Intelligent Tutoring Systems (ITSs); for an overview the reader is referred to (Frasson, 1990). Training systems for symbolic calculation and problem generation are described in (Yibin, 1992) and (Nykaenen, 2000). An automatic adaptation of multiple-choice questions is described in (Huang, 1996). A method to form opportunistic groups as a function of the individual know-how is described in (Ikeda et al. 1997). Schulmeister addresses the psychological importance of feedback from the online system to the learner and the opportunity to somehow control the program (Schulmeister, 1997). He argues that control by the student leads to induced benefits such as the development of certain meta-cognitive skills. Also, since artificial intelligence techniques alone are often unable to fully adapt the behavior of the system to that of the learner, he proposes a hybrid model with system feedback to the learner as well as some control on his/her side. We also consider a feedback-based control loop to be a promising compromise between the behaviorist principle of exercising by drill-and-practice and the cognitivist principle of self-controlled learning.

Let us now consider related work at the systems level. Whereas many of today’s learning management systems (LMS) have a built-in exercise system, mostly based on simple multiple choice questions (WebAssign (Brunsmann, 1999), imc’s CLIX-Campus (Clix, 2002), Blackboard (Blackboard, 2002)), they nevertheless do not allow the student to easily start a videoconferencing session. Most LMSs support simple versions of group work, typically with mailing lists, instant messaging and bulletin boards. A self-assessment system for a physics course is described in (Kurz, 2002). This system diagnoses individual knowledge and skills at the transition from secondary to higher education but again offers no videoconferencing facility. The integration of videoconferencing into an online tutoring system is addressed in (Martins, 1994) and (Liang, 2001), but in these projects the tutoring system is not adaptive, nor is performance of the learners measured or role-based group work supported. On the other hand, VITAL (Pfister et. al. 1998) and CROCODILE (Wessner et. al. 2001) support group work with facilities such as chat, audio communication and group awareness but they do not provide adaptive team-centered exercises.

Our main contribution with the CATS system is the online measurement of the proficiency level of the individual learners, the automatic generation of group exercises from templates and the automatic setup of an online videoconference for each group of learners. This reduces learner isolation and enhances motivation and feedback.

The remainder of this paper is structured as follows. In Section 2 we present the pedagogical motivation for our approach. Section 3 describes the design of the CATS system, with an emphasis on group formation, and the integration of the videoconferencing facility. Section 4 presents an example borrowed from a law school curriculum: the setup of role-based, networked teams for “moot courts”, a simulated mock court hearing where the students play the roles of prosecutor, defender and judge. Section 5 concludes the paper and gives an outlook on future work.

2 Pedagogical Motivation

Group exercises play an important role in traditional teaching at all levels of the educational system. They serve many purposes: The student himself/herself has to become active, the teacher or tutor gets feedback on a student’s current level of understanding, and group work is motivating to most students: they enjoy meeting with other people and doing work together. Many theoretical models of human learning include a phase in which newly acquired knowledge has to be explained to others in order for it to become stabilized and thus part of a person’s problem-solving skills. For example, Mayes et al. include a ‘dialog phase’ in their learning cycle (Mayes, 1994); another example is Nonakas “externalization process” (Nonaka et. al., 1995). Also, new research on peer reviewing among students shows that this type of interaction greatly improves the memorization of facts and skills, increases motivation, and is well accepted by students (see, for example (Kern 2002)). We conclude that easy communication between a learner and his/her tutor and fellow learners, at any time, is a very desirable component of any online exercise scenario: “lone wolves” in front of their PCs don’t learn in an optimal fashion. As a consequence, we address the automatic creation of online group communities in our work.
The Group Formation Process

We subdivide the students of a course into working groups; each of which has to solve the same problem. The members of a working group fulfill different roles. The knowledge of the students (and the knowledge to be acquired) consists of a number of items. This structure is illustrated in Figure 1.

![Learning Team Diagram](image)

**Figure 1: The group structure of a class**

The CATS system continuously measures the performance of the students and supports the grouping in dependency on their individual level of performance. We determine the performance of the students based on three key performance indicators see (Liebig et. al., 2003):

- **Proficiency**: Proficiency indicates the level of difficulty up to which the student is able to solve the exercise problems.
- **Reliability**: Reliability (sometimes called "confidence level") is an indicator of how consistent the student is in performing at a given proficiency level. It is the variance of the observed proficiency.
- **Time**: The time a student takes to solve a problem is obviously another important indicator, measured in milliseconds.

To calculate a unified level of performance, we need to combine these parameters into one value. We use the following formula:

\[
\text{performance} = \frac{\text{proficiency} \times \text{reliability}}{\text{time}}
\]

To use the group work facility the teacher has first to define the learning objective, than he has to define the learning items. That is important in order to evaluate the knowledge of the students. In the next step she/he has to create a group exercise and to define roles for the group members. That enables CATS to match the students in working groups.

With that information for all students over all items, we are able to build working groups according to the following rules:

1. Every group must have a knowledge of all items in the problem domain (possible spread over several students).
2. Each group should have the largest possible variance in proficiency levels.

Rule 2 is based on the well-known observation that the transfer information is maximized in learning groups where the level of knowledge differs widely.

The group formation process is illustrated in Figure 2. The letters A, B, C, D and E stand for knowledge items. The CATS system forms groups such that all the necessary knowledge is available in each group, typically distributed over several students.
3 Architecture of the CATS System

We now present the architecture of the Communication and Tutoring System. CATS is a Web-based system that supports online exercises for distance learners. It is designed to be used in various subject areas. The information CATS derives about the performance level of the learners is used for different purposes: to give the learners feedback on their current ranking in the learning team, to form new learning teams, and to automatically set up videoconferences with the other students of the team. The CATS system is based on a client-/server architecture and implemented with Web technology. An overview is shown in Figure 3, with the server on the left and the client on the right.

Figure 3: Architecture of the CATS system
The CATS Server

The CATS server consists of several components. The nucleus is the relational database management system Postgres which stores all the data about learners, groups, teachers, questions, etc. The learners’ performance levels are also stored here. To manage data transmission, feedback messages and the controlled group work we use a Java application as our exercise server. To control communication between the students and the system we also use a server application written in Java. We have implemented several simple functions such as logon, logoff, search, and get status. TCP/IP is used for all communication between the clients and the server. In Java-to-Java communication we use serialized objects. Access to the database is done with a JDBC connection.

For the CATS administrator we have implemented a Web-based PHP interface, which registers new students as well as new applets. The applets are assigned to courses and to special topics within the courses. Also, ranking lists can be requested, and statistical data for course evaluation is available.

The CATS Client

The CATS client provides the user interface to the distance learner. Figure 4 shows a screenshot of the client: On the left side of the screen, a navigation bar is provided to allow a direct jump to specific exercises. The main exercise frame in the middle of the screen contains the Java applet with the dynamically created exercise. The student can practice a topic as often as he/she likes. In each round, a new exercise is offered, with the proficiency level adapted to the student's current performance. When the student has completed an exercise, he/she transmits the results back to the CATS server.

![Figure 4: User interface of the CATS client](image)

Support for Group Work and Roles

In Figure 5 we show the architecture of a group work applet. All the group work applets are based on a generic framework, allowing the CATS Server to control them and keep track of the groups progress. Given this framework the programmer of the exercises/problems does not need any information about the administration of the system. We use state-of-the-art Java concepts such as object serialization to keep the exercises persistent and reflection to integrate new group work exercises into the system at runtime. All the applets have generic parameters for the identification (learning team, working group and roles) and for access control. During the initialization process the applet is parameterized with an appropriate value for “proficiency”, i.e., how difficult it is for the group to solve the generated problem.

The Communication Architecture

CATS integrate audio-/video communication without a media break between computer and telephony. We use two different A/V communication technologies: SIP (Session Initiation Protocol) and H.323. When the student clicks on the corresponding button on the screen, an IP videoconferencing session is automatically initiated.
On the right hand side of the client screen, a ranking list of those students is shown who are currently working on the same exercise. Alternatively group rooms are shown (for the working- and for the meta-group). A “callto” URL is integrated to call the selected student/group directly with Microsoft Netmeeting, any other H.323-based tool or a SIP-based tool. For group communication we use an MCU (Multipoint Control Unit) which allows to establish a communication room for each group. Up to four participants can be connected with audio and video, and an unlimited number of participants with audio only.

4 The Moot Court Example

The term "moot" originates from a Scandinavian word meaning a meeting. During the sixteenth century law students met in English Inns of Court where they presented their legal arguments on a given set of factual circumstances (often resembling real cases) before one or several senior lawyers or judges. With such meetings the students gained experience without the risk of damaging a real client’s interests. Various regional, national and even international mooting competitions have developed through the years, such as the renowned Philip C. Jessup International Law Moot Court Competition established in 1959 (elmec, 2003).

Implementation with CATS

We have built a simple moot court for criminal law with CATS. In a virtual group session, we first evaluate the individual knowledge of criminal law with CATS, then we build groups of learners in such a way that each group has the capability to solve the case (i.e., has a knowledge on all the items involved). In German criminal law we have four items: objective elements of a crime, subjective elements of a crime, illegality, and responsibility.

In the next step we initiate the group applets with the highest possible proficiency level for all these items. Then we assign the students to the various roles in a moot court for criminal offences: public prosecutor, defender and judge.

In our terminology the learning team are all students of the criminal law course during a semester. The working group consists of all participants of a concrete case. A working group is a team of a public prosecutor, a defender and a judge (in our terminology roles). We also provide an additional role, called “reviewer”, which represents an observer of the trial.

Now the students work on the case. The applet controls the different problem solving steps: First, the students perform a brainstorming about all facts and juridical opportunities, then they draw up an outline, then they write an opinion, and at the beginning of the trial proposes the pleading/sentence.

At any time the students have the possibility to start a videoconference with their colleagues who have the same role, this working group or also with other individual students on the learning team (all students in a course).
5 Summary and Outlook

We have presented CATS, a Web-based generic adaptive tutoring system for group work under development at the University of Mannheim. The emphasis in this paper was on the group-forming and controlling functions, based on roles in a team, knowledge items required to solve the problem, and proficiency levels of the students.

The features that distinguish CATS from similar systems are:
- dynamic generation of group exercises
- automatic system support of group formation
- software support on student option to establish at any time a videoconference within the group or with other students

We believe that such a system improves the learning success through group communication and through increased motivation by contact to other learners.

We have borrowed the concept of a moot court from the curriculum of a law school as a concrete example of role-based group work and showed how our CATS system would support this scenario.

Today CATS (without the group work facility) is used on our lectures in multimedia technology and computer networks, as well as in political science.

As future work it is planned to start an evaluation of the group work facility in cooperation with the faculty of law. In the next sub segment CATS could be used in other subjects. To improve the system we are planning to allow the teacher to control the group exercises during the cooperation process.

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