A Tool-mediated Cognitive Apprenticeship Approach for a Computer Engineering Course

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Abstract

Teaching database engineers involves a variety of learning activities. A strong focus is on practical problems that go beyond the acquisition of knowledge. Skills and experience are equally important. We propose a virtual apprenticeship model for the knowledge- and skills-oriented Web-based education of database students. We adapt the classical cognitive apprenticeship theory to the Web context utilising scaffolding and activity theory. The choice of educational media and the forms of student interaction with the media are central success criteria.

1. Motivation

Training a database engineer involves teaching basic theories and models of database technology, training the student in database programming, and allowing the student to acquire development experience in database engineering projects. Educational requirements for database engineering subsume knowledge, skills, and experience – a variety of educational issues that is usually difficult to provide successfully. The practical aspects of this endeavour remind us of an apprenticeship model where an apprentice learns under the guidance of a master to become self-reliant in the subject and to master given tasks, such as a database project, on her own. This endeavour becomes a challenge for the instructor if a course has to be given as a virtual course using the Web as the delivery medium with little contact between instructor and student.

Our objective is to illustrate how the cognitive apprenticeship theory can be utilised to form an educational framework to train database engineers online. We focus on (i) different forms of knowledge and skills involved in this task and how students interact with knowledge and activity media and (ii) additional measures needed to support the student in a Web environment. We illustrate our solution – the virtual apprenticeship model and technological support for this model – using our own course system.

The objective of the instructor in the cognitive apprenticeship model [2] is to support the self-reliant, autonomous learner. An authentic setting and the direct manipulation paradigm are crucial factors. Scaffolding [2] is a support technique that can substitute the master of the apprenticeship model in the virtual world. Activity theory [6] explains the principle of tool mediation. Web-based software tools handle the student's interaction with the course content. A constructivist style of education shall be facilitated [1], allowing the student to construct knowledge and obtain experience through active participation. Primary learning objectives are the understanding of database development and the ability to construct a database.

Our solution to the problem is to see the student as a virtual apprentice for database engineering. The construction of knowledge, skills, and experience via the construction of artefacts in the apprenticeship is essential. An authentic setting and the possibility to produce and manipulate the 'real thing' are central success factors. Understanding databases engineering is a consequence of this process of constructing database systems.

Different educational media can support different aspects of the overall learning process. The World-Wide Web offers new ways for the learner to interact with educational media. Of particular importance are form and level of the students' interaction with educational media (which provides access to knowledge and skills-oriented activities). The correct interaction level is a central effectiveness and success criterion. An educational model determines possible forms of interactions.

2. Educational Model

The cognitive apprenticeship theory forms the backbone of our educational model. However, we develop a variant, the virtual apprenticeship theory, which is also influenced by scaffolding and activity theory, in order to adjust the classical theory to the Web as the educational environment.

2.1 Cognitive Apprenticeship

The cognitive apprenticeship theory [2] addresses the problem of coaching a student to perform a specific task. A student learns through active participation in a task in an authentic setting in close collaboration with a master. The master provides expertise and advice. The process of apprenticeship learning is characterised by increasing control and ownership by the learner. The cognitive apprenticeship theory puts an emphasis on reflection. A first phase of learning is typically coached, followed by reflection. In the final phase, free and self-reliant learning is supposed to take over. An authentic setting is another key element of an apprenticeship model. Its allows a learner to train with or within the subject of concern itself, i.e. to directly manipulate course-relevant artefacts.

Often in apprenticeships the production of a relevant artefact is central in the final examination. It is the central (visible) learning outcome that demonstrates the skills acquired during the apprenticeship. The cognitive aspect in the apprenticeship theory refers to the acquisition of different types of knowledge and learning processes. Two problems require the adaptation of the apprenticeship approach to a virtual apprenticeship model. Firstly, the interaction with the coach needs to be replaced by software agents as facilitators - we use scaffolding. Secondly, the provision of teaching and learning through tools in general needs to be explained - we use activity theory.

2.2 Scaffolding

The term scaffolding refers to a temporary support framework that is used in the construction of buildings. Scaffolding is needed in the construction process, but will be removed once the building process is advanced and the building supports itself. Scaffolding has been suggested to support learners in their learning effort. The objectives are self-reliant learning and the achievement of competency in a domain. Classically, scaffolding refers to support learners get from interaction with experts, teachers, and peers through learning material, feedback, and demonstration [2].

In the presence of computer support, the notion of scaffolding needs to be adjusted. The instructor's role in providing the scaffolding support is taken over by a software agent. This allows innovative forms of support, but there is also the difficulty is to capture the usually verbal communication and coaching process between an instructor and a learner in a virtual Web-based setting.

2.3 Activity Theory

In a Web environment, instructors can be replaced by agents that control learner activities. Activity theory is a framework that can help us to adjust educational concepts to the Web and other computer-based environments. Activity theory is a conceptual framework that describes structure, development, and context of computer-supported activities [6]. Its emphasis on agents in the interaction between learners and their environments explains the principle of tool mediation - the key problem for the virtual apprenticeship model. These agents – tools in some form – facilitate the interaction. These tools shape the way humans interact with reality. Tools - educational media in our case - reflect experiences other people such as the master in the apprenticeship approach have made in trying to address similar problems. This experience is accumulated in structural and behavioural properties of the tool or medium. A teaching and learning environment is a tool that provides a student with access to a part of the reality – the course subject – through educational media guided by structural and behavioural rules defined by the instructor.

3. A Web-based Database Education Tool

3.1 Knowledge and Skills

Central to our educational system are the different forms of knowledge and access to educational activities. We distinguish declarative knowledge (facts) and procedural knowledge (instructions). Apart from the acquisition of knowledge, other forms of expertise are essential for database engineers. The skills, i.e. the ability to develop a database application, required for a database engineer go beyond declarative and procedural knowledge and involve experience through practical database development activities. Knowledge in a database course is provided in various forms ranging from theoretical declarative to development-oriented procedural knowledge. Skills acquisition is facilitated through active learning features. Educational media implement the features of the virtual apprenticeship model. Educational media provide access to knowledge and skills-oriented activities.

Declarative knowledge is usually presented in lectures. This material provides background, i.e. theories, concepts and other foundations that are essential for database development. Procedural knowledge in relation to system activities is often explained in form of tutorials through animation or simulation of system activity - something that is usually observed by the student. These activities are reactions to student input, executed by the system. Procedural knowledge in relation to student activities is usually presented in form of laboratory work. This complements the tutorial material. It focuses on practical work done by student. Procedural knowledge is involved indirectly - skill acquisition is the goal of the activities.

The educational theory determines how the interaction between student and educational media can take place. The interaction of a student with knowledge representation and skills activities through educational media is the key issue.

3.2 Access to and Interaction with Knowledge

Hypermedia research offers a variety of solutions for the problem of representing knowledge, ideally controlled by the student [5,7]. Data and process visualisation can illustrate data structures and processing of data in any context. The simulation of complex systems, such as database management systems, is an approach that represents declarative and procedural knowledge.

Besides the problem of representing knowledge, we aim to facilitate skills acquisition, and even to enable constructive knowledge acquisition through skills training. Our focus is more on the activities and the learning process design, i.e. on the dynamic dimension of learning rather than the static representation of knowledge. Interactivity between student and educational media - to facilitate both access to knowledge and activities - needs to be embedded into a coherent educational model. This change of focus towards the process is a necessity for computer-based teaching and learning systems.

	lecture	**tutorial**	**lab**	**assessment**
knowledge skills	declarative	declarative, procedural	proced. skills	knowledge
purpose	background knowledge, theory	decl.+proc. knowledge visualisa-tion	active learning, training, feedback	self-assessment
content type	foundations + principles	visualisa-tions	practical activities	feedback, MCQ
extent	complete (theory)	focussed	complete (practical)	complete (theory)
media	visual and audio	animation	interact.	interactive

Table 1. Characterisation of educational features.

Learning in an authentic setting is a crucial element of apprenticeship models. In our case, we need to integrate a teaching and learning environment with a database development environment. The activities that are supported through the educational media in the system are the core activities of database development. We have incorporated educational features into a full-scale database environment.

The effectiveness criteria for a virtual apprenticeship model comprise essentially two elements. Firstly, exam results and other performance data - data is easy to obtain - can be used to assess the acquisition of knowledge. Secondly, the ability to competently carry out database projects - data is difficult to obtain - addresses apart from knowledge the skills acquired and practical experience.

3.3 Implementation of the Environment

Database engineering is about the techniques and methods for the development of database applications. The development process consists of several stages:

- design: using a graphical design notation
- implementation: convert designs to database definitions
- deployment: retrieval/manipulation of database objects
- optimisation: analysis and improvement
- extension: features for embedded/large-scale systems

The overall learning objective is to enable a learner to develop a quality database application, i.e. to master the essential design and implementation languages, and to be able to assess and improve the quality. The necessary knowledge and skills are demonstrated in a project. The virtual apprenticeship model guides the implementation of educational features in our system (Table 1), i.e. the various forms of knowledge and skills-oriented activities. We follow a dual mode approach, with online lectures and tutorial (supported by assessment features) providing a coached presentation of conceptual background and basic techniques and labs providing an environment for self-reliant project work.

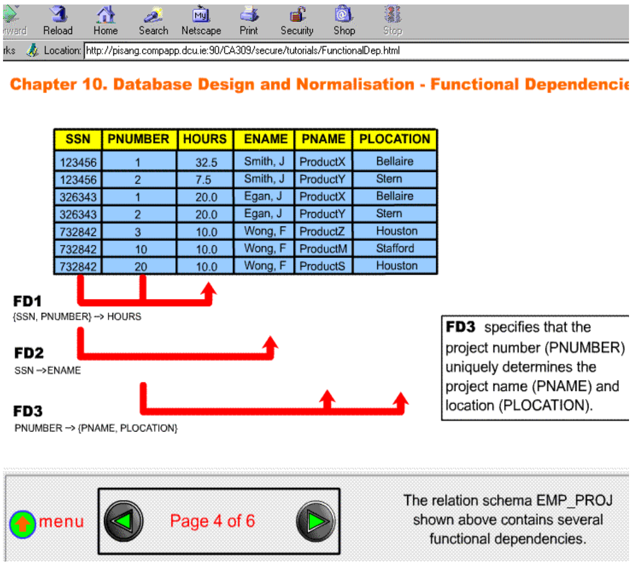

Figure 1. Optimisation tutorial animation.

- Lectures: synchronised audio and visuals resemble the classical lecture; however, the presentation is controlled by the student.
- Tutorials: animated illustration and simulation of key elements that relate to functionality and properties of database environment. We used animations to create short ‘films’ that illustrate various forms of graphically represented data and processing of data, see Fig. 1.
- Labs: support of skills training and project work in relation to the database development process, which subsumes the activities design, implementation, and optimisation, see Fig. 2. Interactive Web technologies including HTML forms and Java applets for the interface, Java servlets for the middle tier, and database support for the backend have been used.
- Assessment: self-assessment through input correction and multiple choice questions – implemented through Java applet technology – is an essential scaffolding element supporting the autonomous learner.

In order to successfully implement the project, a student would have to address each stage of the development process. Each stage involves different problems. The two modes – coached and self-reliant – provide the necessary means to address these problems. These modes are complementary, integrating background (knowledge) and application-oriented (skills) education. In each of the stages, students make progress towards the overall solution of the problem. Starting with the problem description, the student would, depending on current knowledge and skills, either directly attempt a problem solution in the lab environment or decide to learn and practice first using lecture and tutorial features. The assessment features support this decision. For instance, in the optimisation stage, the student could either start the optimisation process or could decide to attend the virtual lectures giving the background and to work throught the animated tutorial sessions (Fig. 1) that explain the purpose and functionality of the optimisation tools in the lab environment. The use of these different features can occur concurrently – something that is not possible in the classical classroom-based third-level education. For each of the stages, a student would, in an interative process, assess her knowledge and skills, and decide to either solve the problem directly or participate in learning actitivities first.

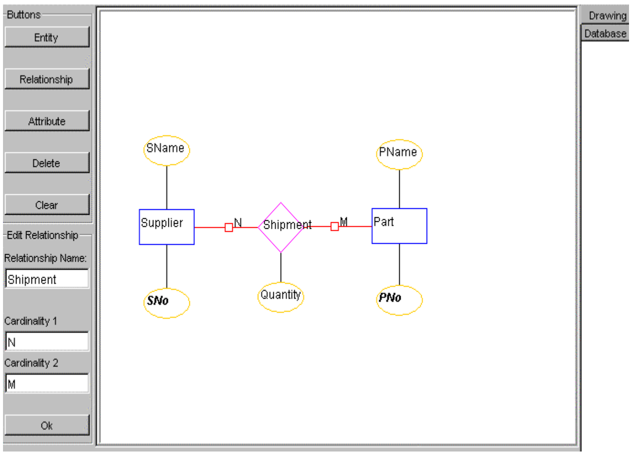

Figure 2. Design lab (with database access).

In particular labs need to enable complex activities involving procedural knowledge and facilities to acquire skills – essential for the realisation of the apprenticeship model and providing an authentic setting for the meaningful, problem-oriented and constructivist project work [1]. The development tools that we have implemented include a graphical design tool, a transformation tool, a programming interface, and an inference engine. These tools together form an integrated, shared workspace, in which the project artefacts are developed over a period of time. In our case, an underlying database system provides the workspace storage and access infrastructure for team-oriented project work results.

The tutorial plays an important role in combination with the labs. In an authentic setting, students interact with the environment (e.g. a database system) through lab features. The tutorial features explain the processes within the environment (e.g. a database system) that occur as a reaction to student input (or another form of interaction). For example, the normalisation tutorial (Fig.1) animates the effect of optimisation tools on stored database objects. Tutorials and labs address internal processes of both the environment and the human, respectively, that are consequences of the interactions between them.

In line with activity theory, these tools reflect our experience in teaching database students and developing database applications through their structural and behavioural properties. Scaffolding – guidance, feedback features, context pointers, and advice – is a central educational feature that represents the master of the apprenticeship in our virtual learning environment.

4. Evaluation

Besides student opinion and performance, learning behaviour is a key factor in online learning evaluation [4,8]. Central evaluation results shall briefly be discussed.

4.1 Behaviour

We have analysed how students interact with educational media and how different features have been combined – information that is crucial in the analysis of the effectiveness of our educational model. It can show us how self-reliant and able to work on project students have become during the course by looking at the interleaving and sequencing of learning and project activities.

The combined use of different educational features is required to learn how to develop a database application. The course infrastructure links related educational features together. A behavioural pattern analysis (based on data mining techniques) shows that 84% of all learning sessions actually follow a pattern of mixing interactive lab/tutorial and scaffolding material at the same time. This technique also confirms that in 77% of all tutorial and lab sessions students have accessed lectures material at the same time.

Often, the change of behaviour is an important element of the learning process, e.g. fading use of scaffolds is expected in an effective scaffolding implementation. The absolute numbers of scaffold requests have been reduced to around 35% in later learning sessions compared to the first, which shows the increasing self-reliance and thus the effectiveness of this concept.

4.2 Performance

Performance in exams and other forms of assessment is an important effectiveness criterion. Improvement of coursework and exam results is one of our instructional design objectives. Over the past couple of years we have constantly enhanced and extended our interactive features. Over the same period we have observed a steady improvement of related exam and coursework results by around 2% percent each year over a four-year period.

4.3 Student Opinion

Student attitude and opinion are important evaluation aspects. Our surveys showed a strong overall acceptance of tool-mediated apprenticeship learning as the pedagogical approach. Asking students to compare traditional and virtual labs produced no clear favourite, which clearly demonstrates that students accept virtual tutorials and labs as equally suitable and effective. We asked the students about their preference of delivery mode with respect to performance in exams. The opinion was split. Again, this shows that virtual tutorials and labs are accepted as at least as good as traditional ones in supporting one of their major objectives, i.e. good coursework and exam performance.

5. Discusssion and Conclusions

An online course integrating various forms of learning activities in an authentic setting goes far beyond the classical provision of lecture material online. We have embedded our solution to training database engineers online into several educational models achieving a constructivist style:

- The cognitive apprenticeship theory is the central theory that supports teaching and learning ideally where a knowledge/skills mixture is required.
- Activity theory explains tool-mediation, which is essential for Web-based teaching and learning systems such as our database engineering course.
- Scaffolding is a supporting theory addressing the autonomous, self-reliant learner, which is needed to adjust the apprenticeship approach to the Web.

Our implementation shows the feasibility of the virtual tool-mediated apprenticeship model. We have evaluated the effectiveness of the approach for our database course. The effectiveness of the virtual apprenticeship model has been analysed in terms of two measurable criteria: performance and ability to do projects. Furthermore, student opinion and learning behaviour have contributed valuable information. Students accept the approach - expressed through their behaviour and opinion. Surveys showed that the students appreciate feature implementations that are based on the apprenticeship theory, e.g. the mixed presentation of declarative and procedural knowledge in an authentic setting. The student performance has improved steadily over the past years, during which we constantly improved the system.

The transfer of results to other subjects is an important question. The virtual apprenticeship model is suited for subjects that are strongly practically based and that involve any form of machine-processable student input. Our system demonstrates how a variety of activities from graphical design, theoretical components and language processing to simulations and animations can be facilitated.

The importance of the appropriate level of student interaction with educational or knowledge media is stressed in [9]. In their experience classical text-based and editable material for online lectures has been more successful than animations, since students can interact with text through annotation by personal remarks. Often a distinction is made between educational content aimed at developing conceptual knowledge and analytical skills on one hand, and skills development and memorisation on the other [10]. The students' motivation in our case is the acquisition of skills, rather than knowledge. Consequently, the form of interaction with course material supporting active learning or skills training, expressed in our virtual apprenticeship model, is different from knowledge-based learning. We feel that the authentic setting and the activities we support allow students to adequately interact with skills-oriented educational media.

The design of authentic activities is a central principle of constructivist learning [3]. We have provided authentic features that are integral elements of common database development and management systems. However, in order to support the acquisition of skills and experience the integration of knowledge-oriented educational elements and authentic features was essential in our case.

Acknowledgements

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