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The Role of the Teacher in Computer-Supported Collaborative Inquiry Learning

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The Role of the Teacher in Computer-Supported Collaborative Inquiry Learning

Abstract

The article presents an analysis of practices in teaching with computer-supported collaborative inquiry learning environments. We describe the role of the teacher in computer-supported collaborative inquiry learning by five principles which span the whole instructional process, from the preparation of the lesson up to the assessment of learning achievement. For successful implementation of computer-supported projects the teacher has to (1) envision the lesson, (2) enable collaboration, (3) encourage students, (4) ensure learning, and (5) evaluate achievement. We analyse classroom scenarios provided by eight teachers or mentors who implemented one of four different approaches developed by multimedia researchers: WISE, Modeling Across the Curriculum, Co-Lab, or ReCoIL. Teachers or mentors responded to a semistructured questionnaire about their experiences in implementing the inquiry lesson. A comparison of different classroom scenarios according to the mentioned five principles informed our analysis of teacher activities that contribute to the success of student inquiry while using such technology-enhanced approaches. We conclude with a discussion of the often neglected role of the teacher in computer-supported learning.

Keywords: information technology, inquiry-based teaching, teacher actions, collaborative inquiry learning, teaching model

Introduction

The level of information technology equipment in education has continually increased within the last years. Computers and the Internet are now available in nearly all European schools (European Commission, 2006). Despite well-equipped schools, computer use for educational purposes is rather low. In Germany, for example, according to results of the Programme for International Student Assessment (PISA) only 31 percent of the students report on regular exercises with computers (Senkbeil & Wittwer, 2007). For comparison, in all investigated OECD countries the rate of regular computer use in schools is 56 percent (Senkbeil & Wittwer, 2007).

The challenge we face is how to transfer evidence-based results and principles of multimedia research (Mayer, 2005) into classrooms. A key element of this challenge is the role of the teacher. Constructivistic theories often describe teachers as coaches or moderators of learning (Collins, 2006; Volman, 2005). However, first of all they are decision-makers. A teacher decides whether multimedia tools are integrated into lessons and open possibilities for students to gain knowledge and new experiences (Dexter, Anderson & Becker, 1999).

There are a number of reasons why teachers decide against computer-based instruction: these can be temporal, spatial, technical, or personnel. Many teachers, particularly in Germany, do not regard multimedia instruction as effective in the classroom and consider other teaching methods to be superior (European Commission, 2006). In addition, not enough research exists about how teachers ought to act during computer-supported instruction when they are not in the traditional role of teaching in front of the class (van Joolingen, de Jong & Dimitrakopoulou, 2007). Many current instructional approaches lack a clear definition of the teacher's role in computer-supported instruction. If our goal is to promote multimedia learning environments effectively, we need to think about how teachers are integrated into the process of knowledge acquisition and which role they take.

In this paper, we introduce an instructional approach for the role of the teacher in computer-supported collaborative inquiry learning. It encompasses five principles ranging from the preparation up to the assessment of the lesson. To illustrate the usefulness of the instructional framework, we present results from teacher observations and teacher interviews related to the use of four computer-supported learning environments from our scientific network.

Teacher's Role in Computer-Supported Collaborative Inquiry Learning

The central role of the teacher in implementing technical innovations in the classroom is widely recognised (Ertmer, 1999; Smeets & Mooij, 2001; Williams, Coles, Wilson, Richardson & Tuson, 2000; Voogt & Plomp, 2001; Webb & Cox, 2004). Therefore, special attention must be paid to ways of supporting teachers in performing technology-enhanced instructional tasks (Barton, 2005). Otherwise, computer-based instruction will be a possible but not a necessary complement to traditional teaching methods (Hadley & Sheingold, 1993). Additionally, meta-analytic results corroborate the assumption that computer-assisted instruction will lead to equally high and sometimes higher academic achievement than conventional instruction (Christmann & Badgett, 2003; Christmann, Badgett & Lucking, 1997; Schacter & Fagnano, 1999; Vogel et al., 2006). In this respect, it seems unjustified if teachers treat technological tools for instructional purposes with great reserve.

Ertmer (1999) differentiates between first- and second-order barriers for why teachers oppose the integration of technology into their curriculum. First-order barriers are described as extrinsic causes and include lack of access to computers and software, not enough time to plan instruction, and insufficient technical and administrative support. Many first-order barriers can be overcome by providing additional resources and training of computer skills. Second-order barriers encompass intrinsic causes such as teachers' beliefs about teaching and computers, established instructional practices, and unwillingness to change. These causes cannot easily be modified and hinder the meaningful use of technological tools in the classroom. Ertmer (1999) concludes that rather than focusing on technology and developing computer literacy, teachers might be more effectively supported by new visions for teaching and learning with technology. In this regard, an instructional approach targeting the role of the teacher might help to promote computer-supported learning in classroom practice.

In the past, a top-down approach was often pursued that prescribed in great detail how tasks are to be done (Krajcik, Blumenfeld, Marx & Soloway, 1994). This is not appropriate for computer-supported learning environments because teachers have to react very flexibly to varying requirements of the instructional technology and of the students. Therefore, it is necessary to connect a vision of an ideal teaching behaviour with the actual demands of computer-assisted instruction and not set the boundaries for teacher behaviour too small.

Webb and Cox (2004) advocate such a relatively broad approach for pedagogical practices relating to information and communication technology use. In the centre of their approach are affordances provided by the teacher or the technology. These affordances can be described as inquiry-based processes like investigating variables in an experiment, testing hypothesis, making predictions, or applying ideas (Webb, 2005). Affordances elicit learning activities that have a direct impact on students' knowledge, understanding, and skills. The framework of Webb and Cox (2004) recognizes not only teachers' activities but also their knowledge, beliefs, and values. This feature is crucial because it has been shown that wrong beliefs such as 'no teacher input is necessary during a computer lesson' prevent supportive activities for the students (Wood, 2001).

We concentrate our statements on the teacher role on a certain area of computer-assisted instruction: collaborative inquiry learning. This format combines elements of scientific thinking and procedures such as making predictions, planning investigations, interpreting data, drawing conclusions, and building models with the social element of collaboration between peers. The aim of collaborative inquiry learning is that students understand fundamental aspects of generating scientific knowledge and recognise that knowledge construction is not an individual affair but a joint task. In this learning process, technology adopts a supporting function. It provides assistance if students have difficulties in understanding content, need instructions how to conduct certain procedures, or want to interact with other learners to answer difficult questions conjointly.

Teaching and learning are closely intertwined areas. While we focus on the role of the teacher in computer-supported collaborative inquiry learning, we implicitly assign a certain role to the learner. In accordance to socio-constructivist theories, collaborative inquiry learning demands an active, constructive, and self-regulated learner sharing his knowledge with peers (Noss & Hoyles, 2006; Salomon, 1993; Shuell, 1996). The learner has to be active in the sense that he is responsible for the learning process (Somekh & Davies, 1991). He has to be constructive by building mental representations of the learning material. The learner has to self-regulate the learning process by use of motivational, cognitive, and metacognitive strategies and resources. Finally, the learner should be willing to communicate and collaborate with other students to reach common learning goals. This picture of the learner should be kept in mind when we discuss teacher's tasks.

We describe the role of the teacher in computer-supported collaborative inquiry learning by five principles. These principles span the whole instructional process from the preparation of the lesson up to the assessment of learning achievement. We consider each of these five principles as helpful for facilitating computer-supported collaborative inquiry learning. Our expectations are that teachers who take these broad instructional principles into consideration for the arrangement of their computer-supported lessons can lead classes to higher learning outcomes. The principles as such are not new. On the one hand, they base on the literature on constructivist learning theories and the application of information and communication technology in the classroom. On the other hand, they are derived from the manifold practical experiences the authors gained during teaching in computer-supported learning environments. For ease of recall, all principles start with an E.

(1) Envision the lesson

In the preparatory phase of the lesson, the teacher has the role of an organiser. He considers technical eventualities and plans lesson structures in advance. The teacher has to affirm that the whole learning environment, including classroom equipment, worksheets and teacher-designed activities, is suitable for students' self-regulated inquiry activities. Students must be clear how to operate the software and what learning goals they pursue. In post-lesson interviews, Hennessey, Deaney and Ruthven (2006) showed that teachers know about the necessity to become familiar with the handling and the content of the software before they start their lesson. Ideally, the learning software supports the teacher in parts of these organisational tasks. For example, in ReCoIL an access point provides a sample of worksheets with different foci on the topic, information about experiences from other teachers, preparation time, or preparations to be done.

(2) Enable collaboration

Collaborative learning is a situation where two or more learners engage simultaneously in a problem-solving or learning task (Dillenbourg, 1999). Meta-analyses on learning with technology indicate that students learning in small groups compared to individual learners have cognitive and affective advantages (Lou, 2004; Lou, Abrami & d'Appolonia, 2001; Susman, 1998). While student collaboration is easily established, it is not guaranteed that effective learning is taking place (Webb & Cox, 2004). The role of the teacher is to organise collaborative learning in a way that students interact well with each other and exchange knowledge and practical instructions (Wessner, Schwabe & Haake, 2004). The teacher has to think about size and heterogeneity of groups and which rules are valid for collaboration. Students' knowledge grows through mutual supplementation of sometimes conflicting opinions and ideas or through learning from the more experienced ones. In some difficult cases, students still need to rely on the knowledge of the teacher. This view is also shared by socio-constructivist theories of knowledge acquisition, which are based on ideas of Piaget (1926) and Vygotsky (1978).

(3) Encourage students

During collaborative inquiry learning, the teacher takes on the role of a coach or navigator (Volman, 2005). He is not in the role of a technical assistant and silent bystander but promotes and encourages students to self-regulate learning. The teacher uses teaching methods as described in the cognitive apprenticeship approach (Collins, 2006; Collins, Brown & Newman, 1989). He coaches by observing the students while they carry out collaborative inquiry tasks and answers questions or clarifies difficulties. The inquiry teacher scaffolds by taking into account students' prior knowledge and abilities and provides help in a way that students perform tasks mainly on their own. A special difficulty arises from the fact that learners take individualised routes through the learning program. Therefore, the inquiry teacher has to react with great flexibility to eliminate problems and provide individual help. Another important aspect is teachers' abilities to motivate student learning when they show difficulties in getting started or are not willing to take the next step. Sometimes students only need an initial spark and then perform the activity on their own (Ruthven, Hennessy & Deaney, 2005).

(4) Ensure learning

In collaborative inquiry learning, the teacher is in the position to train and develop students' domain-specific abilities and skills. He has to find ways to monitor learning progress and to ensure learning. As a strategy to secure classroom learning, the cognitive apprenticeship principles of articulation and reflection can be applied (Collins, 2006). Articulation of students' thoughts informs the teacher about misconceptions, wrong reasoning, or problem-solving deficits. Reflection is a suitable means to revise a mental representation of a problem situation and lead students to a higher level of understanding. In technology-enhanced collaborative inquiry learning this can also be supported by the learning software, for example, by storing working protocols or learning paths like in Pedagogica (Buckley et al., 2004). The teacher may also provide students with opportunities to present inquiry results in the classroom, discuss them in groups or chalk up findings on the blackboard.

(5) Evaluate achievement

At the end of collaborative inquiry learning, the teacher must carry out an assessment of students' achievement in a suitable manner. Assessment gives students feedback about their progress, strengths, and weaknesses, and allows a way to evaluate instructional effectiveness and curricular adequacy (Hambleton, 1996). Traditional methods like conversation in the classroom and achievement tests are not sufficient assessment criteria. More adequate is the assessment of a learning process or a learning product that is created by use of the inquiry software. For example, this could be students' elaboration of a scientific model. Intraindividual model changes help to evaluate learning processes and interindividual model comparisons can be a means to assess learning products. A formative assessment component such as in the ThinkerTools Inquiry Project (Schwarz & White, 2005; White & Frederiksen, 1998) where students engage themselves in so-called "reflective assessment" can be helpful as well. Teachers who conduct formative evaluation in the classroom and therewith adapt the teaching to the students' needs produce significant and often substantial higher learning outcomes (Black & Wiliam, 1998; Black, Harrison, Lee, Marshall & Wiliam, 2004).

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please insert Table 1 about here

The five principles on the role of the teacher in computer-supported collaborative inquiry learning together with a short description are shown in Table 1. In the following section, the role of the teacher is more closely analysed. Two interrelated questions build on the focus of our studies: How do teachers act during computer-supported collaborative inquiry learning? Do the five proposed principles reflect the real behaviour of the teachers?

Method

For research purposes, we selected four learning environments from our scientific network on collaborative inquiry learning: WISE, Modeling Across the Curriculum, Co-Lab, and ReCoIL. Two teaching scenarios of every learning environment show how teachers adapt to their modified role in the classroom.

Data were collected by means of a semistructured questionnaire subsequent to computer-supported instructional units. Questionnaire responses stem from the teachers themselves or from an observer who was present in the classroom to support collaborative inquiry learning on the technical level. The questionnaire contained items about the experience of teachers in computer-based instruction, topic, school grade, students' age, duration of instruction and also required a detailed description of all teaching activities as well as media application. Data to which we refer selectively in the following scenarios were collected in five interrogative blocks. These were titled preparation, collaboration, scaffolding, role of the teacher during classroom practice, and assessment, each containing one to three questions. These blocks cover the areas in which teachers have an influence on mentoring students' collaborative inquiry activities (Lakkala, Lallimo & Hakkarainen, 2005). Thus, information with respect to the five proposed principles was gained. Example questions are: Did you modify or add materials (envision the lesson)? What was the role of collaboration (enable collaboration)? How were students supported by the teacher (encourage students)? How was it ensured that learners reach their goal (ensure learning)? How were results presented (evaluate assessment)?

Interview and observation methods were not selected to draw an entirely objective picture of the real events in the classroom, as it might have been possible by videotaping.

Teachers and observers can err in judging the lesson or can be tempted to give a too positive judgement about the lesson. However, the advantages of the chosen methods are to provide a practical impression of how teachers act during computer-based inquiry learning and to give information about the extent to which they align their lessons according to the five proposed teaching principles.

Teaching with Collaborative Inquiry Learning Environments

WISE Learning Environment

WISE is an acronym for Web-based Inquiry Science Environment and is intended to expose students to key scientific concepts and methods via the Internet (Linn, Clark & Slotta, 2003; Slotta, 2004). WISE is the predecessor of TELS (Technology Enhanced Learning in Science) which provides more current inquiry learning modules (Linn, Lee, Tinker, Husic, & Chiu, 2006). WISE projects run on a central server and are delivered via a web portal to the learners. Over fifty projects from various science subjects are currently available. Each project consists of a sequence of web pages grouped into thematic sections. The pages provide media-enriched information on a problem context and on scientific content. Further, students have access to online activities, such as interactive simulations. At various points in every section, learners are asked to answer open-ended questions in an electronic notebook. These questions require noting prior knowledge, making a prediction, focusing on specific parts of the information, or summarising results, respectively. Student answers are saved on the server and may be assessed by the teacher or by researchers. Detailed information on the WISE inquiry approach is given by Slotta, Jorde and Holmes (submitted). Two projects from the field of Biology and Life Sciences are assessed in this study.

The Mitosis and Meiosis project was designed for Biology classes of grade 9-12. The learning sequence provided by the project is as follows: Section 1 introduces the inquiry question "How do cells reproduce?" together with figures and a movie of cell division.

Section 2 presents the mitosis phases and a cell counting activity. Section 3 describes cancer and leukaemia in particular as well as their relation to cell reproduction. Section 4 presents the phases of meiosis and its role in sexual reproduction. Section 5 highlights the causes for genetic diversity and allows students to perform a dragon breeding activity. Section 6 provides information on the Down's syndrome. The final section 7 presents a side-by-side comparison of mitosis and meiosis phases.

The second project, Malaria Introduction, is suitable for Biology classes of grade 6-12. It deals with different approaches to control the spread of malaria. The project is divided in three sections: The first section introduces the problem by telling the story of a small African boy infected with malaria, by giving insight into the statistics of malaria and its global distribution. The next section informs the students about the life cycles of the malaria parasite as well as of the mosquitoes as vectors of the parasite. The third section focuses on some strategies to prevent the spread of malaria (like killing mosquitoes, developing vaccines, teaching people) as well as evidence of their effectiveness. As a final activity the project stimulates a student discussion on control strategies by providing an online forum.

Teaching with WISE

Meanwhile, WISE inquiry projects are so intensively researched that much is known about the teacher's role (Linn & Hsi, 2000). Experience has shown that teachers differ considerably in their interactions with students when teaching with WISE (Slotta, 2004). However, teachers also change their classroom practices over time. For example, individual teachers were able to improve their teaching style by feedback from mentors and support from the curriculum and other professionals (Slotta, 2004; Williams, Linn, Ammon & Gearhart, 2004).

In the following scenario, we describe exemplarily styles of two teachers, pseudo-named Mike and Tina, and examine how they fit with the proposed five principles. Mike has been an observer of WISE many times but it is his first time using a WISE project as a classroom teacher. He has chosen the project mitosis and meiosis so that students can explore linked concepts via a hands-on inquiry format. For Tina, it is her first time teaching with WISE. Her instructional goal was for students to acquire a basic understanding of the malaria cyle, transmission, care and prevention. While Mike worked mainly with 10th graders, Tina conducted her lessons with 6th graders. The differences in teaching experience, topic, and grade do not permit a real comparison between teachers. These case examples rather illustrate the breadth of application of the proposed five principles.

Mike had to deal with some responsibilities for the preparation of his lesson. He edited some of the project text for clarity and added a bit of humor where it seemed to make sense. This seemed to be necessary because some of his students needed much more time to read materials thoroughly and had struggles with vocabulary. He also organised technical support from members of the WISE team and helped students to become acquainted with signing in, learning the interface and fulfilling other technical requirements. He organised collaboration in a way that students could collaborate within their team and across teams but still felt individually accountable. During classroom practice, he encouraged students by multiple means: trying to engage students in brief talks about findings, circulate around the room, offering feedback, help, and praise to students. For learning purposes, Mike used an additional tool on the WISE system called "challenge questions" that gives students feedback on the accuracy with which they are reading text information. He began each class by letting students write down the most interesting thing from the previous day and ended the project with a classroom discussion. Mike found several ways to assess students' achievement. He reviewed students' reading thoroughness and accuracy of content retention through the tool "challenge questions" and evaluated written responses created by students during the project. In addition, Mike used a quiz with multiple-choice questions, drawing and visualisation tasks to assess understanding of mitosis and meiosis processes as well as related concepts. Table 2 summarizes Mike's instructional behavior with WISE. All five categories provide hints for the implementation of the proposed principles of teacher's role in computer-supported collaborative inquiry learning.

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please insert Table 2 about here

Tina started her project through the teacher support centre and the user portal in WISE. There she received sufficient information for the malaria project that no extra preparation for the lessons was necessary. Her students worked collaboratively at computers because the WISE software is designed to be used with a learning partner. Prompts and probes of the programme encourage students to reflect knowledge and exchange information. To scaffold collaboration, students completed debate worksheets which require students to present and defend arguments. During the lessons, Tina initiated some exchange of information among students, tried to anticipate comprehension difficulties, answered student questions and resolved technical problems. She monitored students' progress online as well as the quality of their responses. By asking single students to explain responses and by conducting classroom discussions, she kept a close watch on learning. Results of student work were stored online which allowed her to evaluate student progress and to assess the quality of student responses. The right column of Table 2 sums up Tina's teaching behaviour. In comparison to Mike, her lessons are more conventionally conducted by relying strongly on the guidance of the learning programme.

Modeling Across the Curriculum Learning Environment

The program Modeling Across the Curriculum (MAC) includes comprehensive units for the topics of mechanics, genetics, gas laws, and molecules and atoms delivered to the classroom via the Internet (Buckley et al., 2004; Hickey, Kindfield, Horwitz & Christie, 2003). For this survey, the module Motion Graphs and its classroom usage were analysed. The module, as with most other MAC modules, is designed for use in about one class period. Students work individually through a module on a PC at their own pace. Student collaboration is not built into the MAC projects, but students may ask their peers or their teacher for help when they have difficulties. A module consists of a fixed sequence of pages containing a context description, some content information, focusing hints, and above all manipulable simulations with graphical displays. By manipulating parameters of the simulations and observing the outcomes, learners build knowledge of the related scientific concepts. Student understanding is assessed at nearly every page using different formats such as multiple-choice and open text fields where students can express their ideas. The learning environment provides feedback on students' multiple-choice answers and on some of parameters that students manipulate. There are also some context-sensitive hints provided when answers or manipulations are incorrect. All open-ended responses from the learner are saved in log files available for later analysis.

The selected module Motion Graphs introduces students at the lower secondary level into basic types of kinematic graphs. The driving question of the four-section module is how graphs can be used to describe motion. In the first section, students learn to read position vs. time graphs of a simulated one-dimensional ball motion and to calculate a velocity. The second section introduces instantaneous velocity changes and velocity vs. time graphs.

Teaching with Modeling Across the Curriculum

Deborah and Anne are pseudonyms for two physics teachers using the first and the second section of the module Motion Graph for computer-supported collaborative inquiry learning lessons. Deborah is very experienced with MAC projects, having used them for three years. Anne started some MAC activities in the previous school year and is now applying them regularly.

Deborah prepared for the MAC project by going through the activity herself. She analysed whether the flow of the concepts fit well with students' prior knowledge. Before working on the MAC activity, the 11th and 12th graders completed two calculator-based activities to a similar topic. While working with the Motion Graph section, students sat close to each other that they could ask their classmates questions. Deborah encouraged students to ask her or each other questions to make sure that they understood scientific ideas. She circulated from group to group and helped students to understand the graphs. After completion of the MAC activity, she enabled knowledge construction by giving a situation or a graph on the board that was linked with a question. Students were also quizzed on concepts and graphs and had to answer test questions embedded in the MAC system. Table 3 provides an overview of Deborah's instructional activities that were strongly influenced by the fixed programme structure.

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please insert Table 3 about here

Anne aimed to teach vector addition in two dimensions to 10th to 12th graders. Prior to the researched class period, students had completed the first section of Motion Graphs and now started the second section. Most of the time, students worked individually on the computers. They were supported by the "hints" function that was built into the programme but also sought help from neighbouring students when they "got stuck" or had difficulties. During the computer-supported lesson, Anne circulated around the room, answered questions, clarified information and provided content scaffolding to individual students. Learning was assessed via programme-embedded multiple choice, open-response, and fill-in items. Because of the short time period of just one hour, no inquiry results were presented or discussed in the classroom. Table 3 resumes Anne's teaching style which is quite similar to Deborah's actions. These analyses suggest that the MAC learning environment encourages a particular teaching style.

Co-Lab Learning Environment

The internet-based learning environment Collaborative Laboratories across Europe, or shortly Co-Lab, aims to promote inquiry learning and collaborative modelling of dynamic systems (van Joolingen, de Jong, Lazonder, Savelsbergh & Manlove, 2005). Co-Lab projects are designed for use at the upper secondary level for students between 17-19 years old. Usually, they form a unit of 20-25 lessons. Working on the Co-Lab projects in groups of two or three, students are supposed to acquire inquiry skills by carrying out investigations through experimenting, modelling and incorporating complex information.

A typical Co-Lab project is structured in several modules with each module consisting of a sequence of levels. Entering a level, students receive an assignment to explore a physical phenomenon related to the topic. Students then experiment with a simulation or investigate datasets of the phenomenon and create or extend a graphical model able to reproduce the experimental data. The model at the following level usually is an extension of the model obtained up to that point.

The two main Co-Lab projects, called Greenhouse effect and Water Management, were assessed in this study. In the Greenhouse project students investigate the radiation balance of the earth and human influence on it and build a very simple model of it that is able to reproduce estimated temperature increase caused by CO_2. In the Water Management project students investigate and model the watershed area and runoff of a small river. It was found that these two Co-Lab projects show very similar characteristics according to the questionnaire's categories so that the results can be integrated.

Teaching with Co-Lab

Jennifer and Harold are two German teachers who used Co-Lab projects in the classroom for an extended period of time. Both teachers had no previous experiences teaching with the provided multimedia learning environment. With Co-Lab they pursued similar learning goals.

Besides learning about scientific facts and concepts, students had to learn to carry out inquiry processes and improve in graphical modelling. Jennifer also strived to enhance students' self-regulated learning capabilities through collaboration between student group members.

Jennifer started her Water Management project with an in-depth preparation for the computer-based learning session. Some advanced-level students translated Co-Lab reading materials from English into German. A real water tank experiment was added to ease the imagination of what was happing in the Co-Lab water tank simulation. Finally, Jennifer formulated some tasks for the work phases. In the beginning of the Water Management project, groups of two students were formed. This formation occurred spontaneously and was not influenced by the teacher. Sometimes student pairs merged with another group. The new group of four students had the advantage that they could combine elements of their respective models. Jennifer scaffolded the students on different levels. She motivated a small number of students to get started, introduced the class into modelling and coached modelling activities. To ensure learning, Jennifer imposed a specific structure of modelling steps, each consisting of tasks, modelling activities, presentation and reflection. Through plenum presentation at several points in time each group could access some hints on how to build the model. The teacher enabled transfer of knowledge by modelling in the field of population dynamics but she did not assess students' achievement. Table 4 shows how Jennifer's classroom instruction corresponds to the five principles on the role of the teacher in collaborative inquiry learning. Remarkably, she invested a lot of work in the preparation of the computer-supported session and found different ways to ensure learning but set aside evaluation.

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please insert Table 4 about here

Harold devoted a lot of time for teaching the Co-Lab Greenhouse effect project to advanced level physics students. It lasted six weeks with a total of 26 lessons. Harold prepared his lessons by selecting a general information text on greenhouse effect to introduce students into the problem. In the beginning, he added two real experiments because he thought students needed some hands-on experience. In contrast to Jennifer, he gave the assignment to work on the Co-Lab tasks in groups of 2-3 students. Students came up with the idea to exchange knowledge between groups and Harold encouraged them in this respect. During the lessons, the teacher sometimes guided students in a whole-class activity or supported groups in using the modelling software and interpreting graphs. Because of the interesting topic, all students were highly motivated and eager to learn. To enhance the coherence of his lessons, Harold used introductory and summary overhead projector slides in each lesson. He arranged exercises to be solved in homework. Furthermore, he controlled the learning progress by short presentations of student results at the end of modelling phases. In the end, the teacher gave an extended written test based on the contents of the Co-Lab project. In Table 4, Harold's teaching behaviour on the Greenhouse effect project is summed up. In comparison to other learning environments Co-Lab projects require a longer preparation time, due to their significantly longer duration. While summative evaluation of student achievement seems to retreat into the background, formative evaluation aspects, not mentioned in Table 4, are of greater importance.

ReCoIL Learning Environment

Resources for Collaborative Inquiry Learning (ReCoIL; http://www.recoil.nl) is an Internet portal of science materials designed to help students learn science domains and skills. The European e-learning project emanates from three other international educational endeavours, namely Co-Lab, Viten and ModellingSpace. ReCoIL projects usually consist of a downloadable Java applet and accompanying HTML or PDF worksheets for students. The applet provides the students with a stock-and-flow model editor, sometimes a simulation or other data source, a table and a graph tool for displaying data and reading materials with background information on concepts needed for the solution. Student collaboration, normally organized by students' worksheets, may or may not explicitly be intended in a specific project. Two ReCoIL projects are described as follows, to provide insight into the learning scenario.

The Diffusion project was designed for the upper secondary level and should be completed in about 90 minutes. In this time, students guided by a worksheet are asked to build a model of a simple diffusion process by using the stock-and-flow model editor. Students' product should be comparable to a given simulation of the diffusion process.

The second example is ReCoIL's Course bending project, originally planned for a double period at the upper secondary level. The students' task is to optimise a speed skiing course for maximum speed. Activities vary from reading background information about important concepts, drawing a static model about the forces on skiers, stating hypothesis on the development of skier's velocity, modelling skier on a slope by using the stock-and-flow model editor, and adapting their model to the conditions of the real track. Finally, they have to report their assumptions, working processes, and conclusions in a mock "board meeting", i.e., to their class who then decide on the ski course's shape.

Teaching with ReCoIL

Chemistry Teacher Martin and Physics teacher Alexandra are two Dutch educators who tested ReCoIL in the classroom. Both had no prior experiences with ReCoIL projects.

Martin chose the Diffusion project with the aim to teach model building of the diffusion process. He started the project by explaining the activity to students and handed out worksheets retrieved from the ReCoIL resources web site. Because of the worksheets, no extra preparation for the lesson was necessary. The 12th graders perceived the worksheet tasks as difficult and were not motivated to support each other and collaborate through the tasks. Martin did not encourage collaboration because students were used to working together in school. During the project, the teacher coached students through the activity and offered help on some issues. Martin showed how to use the modelling tool and to transfer ideas into a model. He talked with students through the assignment afterwards. At conclusion of the project, students presented their models and discussed them in the classroom. Table 5 presents Martin's actions before, during and after the modelling lesson. It is apparent that most of his instructional tasks are concentrated on the time during the lessons.

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Alexandra decided for her ReCoIL project to take the same structured introduction as Martin. She began by explaining the activity of building a sophisticated model for the description of a curved skiing track to 12th grade students and handed out accompanying ReCoIL worksheets. Alexandra's students collaborated at various points and this was reported to be helpful. Collaboration was also a reason for staying motivated during the difficult task and for solving a number of issues that arose. The teacher helped students in working out some mathematical details and discussed student questions not only face to face but also via email. At the end of the project, students gave a presentation to their peers and the teacher checked the model. It was not only the teacher who evaluated student achievement. In addition, peers completed an evaluation form about the presentation. Table 5 summarises Alexandra's teaching activities and relates them to the proposed principles.

Discussion

Up to now, research on information technology in education has given not enough attention to the role the teacher, given the central part that the teacher plays in technology-enhanced classrooms (Ruthven, Hennessey & Brindley, 2004). Rather, multimedia learning research has focused on learning technology and instructional design as well as knowledge, skills, attitudes, experience and behaviour of the learner (Mayer, 2005). Often only a minor part addresses the teacher role which contributes to the fear that multimedia learning environments supersede the teacher or that the teacher has to adopt the role of a quiet observer (Wessner et al., 2004).

In this contribution, we introduced a model that defines more precisely the role of the teacher in computer-supported instruction. The 5E-model encompasses all phases of a project, from the preparation up to the evaluation, and reveals that in no phase of the instructional process the teacher is passive or even redundant. In fact, the teacher holds an equally active role as the learners themselves which deviates considerably from the traditional picture of a technical assistant and silent bystander in the computer-enhanced classroom. Our analyses disclose that teachers envision the lesson, enable collaboration, encourage students, ensure learning, and evaluate achievement. All processes of the 5E-model of teacher behaviour in computer-supported collaborative inquiry learning can be supported by the multimedia learning environments. As our qualitative results of four different learning environments indicate, this does not force the teacher into passiveness. Rather, he has to fulfil a broad range of tasks.

The comparison of four collaborative inquiry learning environments shows that teachers have to meet different requirements. Co-Lab projects seem to be very complex concerning temporal duration as well as preparation. Therefore, with this environment teachers already solve many tasks in the preparatory phase such as selecting and translating texts or adding real experiments. In contrast, the preparatory phase for computer-supported lessons with the other learning environments is less laborious. ReCoIL projects provide additional instructional materials, e.g., worksheets which facilitate teachers' encouragement of collaborative inquiry learning. In addition, the careful structuring of WISE and MAC projects relieve teachers' preparation of computer-based lessons.

Opportunities for collaboration were taken in the projects very differently. Learning environments like WISE, which guarantees collaboration by task design, or Co-Lab, which contains an additional chat function, worked well. However, ReCoIL projects illustrate that collaboration between students cannot be compelled. While in Alexandra's lessons students collaborated well, Martin's students showed no motivation to work with each other. Therefore, learning environments and the teacher have only limited influence on collaboration between peers.

In no cases during computer-supported lessons, teachers behave passively or are only quiet observers. They motivate students for learning, answer questions, clarify difficulties and demonstrate the use of tools. No collaborative inquiry learning environment supersedes the teacher or forces him to play only a minor part. It is interesting that students' knowledge acquisition in the various learning environments is secured in different ways. Worksheets and model presentations like in ReCoIL can serve this purpose. A fixed structure of inquiry steps or a guide for sequencing the lessons like in Co-Lab also appears to be helpful. Moreover, tools embedded in the system like in WISE or MAC can ensure students' learning. The analyses point out that teachers make use of entirely different possibilities to promote learning in technology-enhanced lessons.

The assessment of students' achievement is not necessarily determined through the learning environment. In some cases like in MAC or WISE technology-driven assessment tools are used. In other cases like in Co-Lab formative aspects of evaluation come to the fore. In long instructional Co-Lab units, teachers can evaluate more effectively the inquiry process skills of individual students. It becomes clear that beyond classical instruments for student assessment like verbal participation and achievement tests, teachers often use other opportunities provided through the use of the inquiry environments.

When we examine the multifaceted tasks of the teacher in multimedia learning environments, the question arises whether the multimedia learning environment can assume part of work from the teacher. Our analysis demonstrates that computer-supported learning environments encompass not only possibilities to impart new abilities and skills to learners but can also support teacher's tasks effectively. Often it is enough if, for example, worksheets are provided online which teachers print out and distribute for completion to the students. Another good method of support is to present an exemplary lesson to the teacher. He can take over the structure of the lesson or modifies it in such a way that it fulfils his conceptions and claims. Beside this easy but effective teaching support we regard different computer-based tools as useful.

A possibility to facilitate teacher's work consists in setting up a Knowledge Forum as recommended by Scardamalia (2004). Knowledge Forum is a technology designed to support contributions to a communal database. In the forms of notes, students add models, plans, ideas, evidence, or self-developed materials to a multimedia platform. The teacher can observe how revisions, elaborations and reorganisations are carried out by student groups and even participate in what is happening. He observes knowledge progress and supports learning by helping student groups facing difficulties.

There are also tools which are especially designed to support teachers' tasks in collaborative inquiry learning. Collage (Hernández-Leo et al., 2006) and GridCole (Bote-Lorenzo et al., 2004) are authoring tools specialised for computer-supported collaborative learning. They help teachers to create their own potentially effective collaborative learning design by use of collaboration scripts. These scripts prescribe how students form groups and how they interact and share ideas in order to solve problems (Kollar, Fischer & Hesse, 2006). Instead of trying to create their own collaborative design from scratch, teachers use collaboration scripts as templates or guides from a computer repository to structure student collaboration. To improve inquiry learning processes, we regard the Process Coordinator of Co-Lab as meaningful (van Joolingen et al., 2005). The Process Coordinator enables the teacher to determine specific learning objectives. Thereby, the teacher can work towards the goal that students practise processes of inquiry learning like stating hypotheses, interpreting data, or modelling. Once the teacher has the impression that these processes have been internalised by the learners, he can begin to fade support and check whether students carry out inquiry processes independently.

The technical possibilities should not be the starting point for the development of new learning environments or tools. Crucial are the needs of learners and teachers. With new tools, the teacher should be able to manage tasks of computer-based instruction as schematically described by the five proposed principles more efficiently. A teacher should be able to tackle preparation, realisation and assessment of technology-enhanced projects in an effective way.

The rationale for laying technical innovations' failure at the feet of teachers is rather unfair if teachers are hardly integrated into considerations and developments on computer-based instruction. Of course, it is not enough to bring teachers together in a computer workshop and to hope that their pedagogical behaviour in the classroom will be positively affected. More promising to make changes happen might be a blended approach: Short workshops alternate with periods in school where participating teachers communicate with each other and exchange learning materials (Voogt, Almekinders, van den Akker & Moonen, 2005).

To make further changes happen, we need to develop theoretical approaches on computer-based learning and models around the role of the teacher. The 5E-model encourages teachers to use computer-supported learning environments in creative and challenging ways and establishes the right proportion between learner independence and guidance. However, further investigations on the five teaching principles are necessary to learn more about their effectiveness to improve student achievement. We can also not disprove the hypothesis that investigated teachers' beliefs about computer-based instruction may have had an influence on their classroom behaviour (Webb & Cox, 2004). At the moment, we only know that teachers in different computer-supported inquiry learning environments adjust their lessons according to the five principles. In every phase of the computer-supported lesson, the 5E-model ascribes an active, planning, supporting, or evaluating function to the teacher. Only if teachers know what role they play in computer-supported learning, if they accept the role for themselves and feel comfortable in it, we can expect more widespread dissemination of technology in education.

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Table 1. Five Principles to the Role of the Teacher in Collaborative Inquiry Learning

Principle	Short description
Envision the lesson	Create an image of the lesson, plan and organise student tasks
Enable collaboration	Arrange small groups or pairs so that one can learn from the other
Encourage students	Support learners and provide guidance during knowledge acquisition
Ensure learning	Monitor learning processes and check learning outcomes
Evaluate achievement	Choose suitable means to assess processes and products of learning

Table 2. Comparison of Two WISE Teachers

	Mike	Tina
Topic	Mitosis and meiosis	Malaria
Grade	mainly 10th graders	6th graders
Duration	7 hours	5 hours
Envision the lesson	edit texts organise technical support	no extra preparation necessary
Enable collaboration	students work in pairs and also collaborate across teams	students work collaboratively with a peer students complete debate worksheets students present and defend their arguments
Encourage students	engage students in brief talks about findings answer student questions offer feedback praise students sending written feedback to student notes in WISE	initiate information exchange among students anticipate comprehension difficulties answer student questions ease difficulties with computer use
Ensure learning	WISE tool "challenge questions" provides rapid feedback students write down most interesting thing of previous day classroom discussion at conclusion of the project	monitor comprehension progress ask students to explain responses conduct classroom discussions
Evaluate achievement	review of "challenge questions" review of written responses quiz with multiple-choice questions, drawing and visualisation tasks	evaluate student progress online assess quality of responses

Table 3. Comparison of Two MAC Teachers

	Deborah	Anne
Topic	Motion	Velocity
Grade	11th and 12th graders	10th to 12th graders
Duration	1 hour	1 hour
Envision the lesson	before the MAC activity, students completed two calculator-based labs go through the activity herself	prior to class period, students completed one other activity of the computer learning series
Enable collaboration	students sat close to each other and could ask classmates questions	students sought help from a neighbouring student when they "got stuck" or had difficulties
Encourage students	wander from group to group encourage students to ask questions	circulate around the room answer questions clarify information
Ensure learning	help them to understand graphs give a situation or graph on the board; students work on these and discuss them as a class	provide content scaffolding to individual students
Evaluate achievement	students were quizzed on concepts and graphs students had to answer MAC test questions which counted as a quest grade	program-embedded assessment by multiple choice, open-response, and fill-in items

Table 4. Comparison of Two Co-Lab Teachers

	Jennifer	Harold
Topic	Water management	Greenhouse effect
Grade	12th graders	12th graders
Duration	15 hours	26 hours
Envision the lesson	translate English text materials into German add a real water tank experiment formulate tasks for the work phases	select a general information text on greenhouse effect chose two real experiments which students work on in the beginning
Enable collaboration	form groups of two students which sometimes fuse to groups of four at a later time organisation of collaborative activities was totally up to the students	give assignment to work on the task in groups encourage exchange of knowledge
Encourage students	motivate students for getting started coach student groups during modelling activities often through asking questions	no need to motivate because groups were highly motivated support groups in using the software and in interpreting graphs
Ensure learning	impose a specific structure of modelling steps (task – modelling – presentation – reflection) foster reflection on the content enable transfer of knowledge by modelling in the field of population dynamics student presentations at several points of time	use introductory and summary slides in nearly each lesson arrange exercises to be solved in homework short presentations of student results at the end of modelling phases
Evaluate achievement	no student assessment	extended written test on Co-Lab contents

Table 5. Comparison of Two ReCoIL Teachers

	Martin	Alexandra
Topic	Diffusion	Modelling curved ski track
Grade	12th graders	12th graders
Duration	2 hours	6 hours
Envision the lesson	no extra preparation necessary	no extra preparation necessary
Enable collaboration	students talk about difficulties but do not collaborate because of low motivation	students worked together and that helped them out a lot
Encourage students	coach students through activity help students on some issues show students how to use a tool to transfer ideas into a model	help students in working out some detail discuss questions of students via email
Ensure learning	give worksheets to students talk with students through the assignment afterwards model presentation and oral discussion	give worksheets to students check the developed model presentation of model to peers
Evaluate achievement	no student assessment	peers completed an evaluation form about the presentation