Synchronous Tele-tutorial Support in a Remote Laboratory for Process Control

Authors:

Andreas Böhne, Learning Lab Lower Saxony (L3S), Hanover, Germany, boehne@learninglab.de
Nils Faltin, Learning Lab Lower Saxony (L3S), Hanover, Germany, faltin@learninglab.de
Bernardo Wagner, Learning Lab Lower Saxony (L3S), Hanover, Germany, wagner@learninglab.de

Abstract *— Traditional laboratories in engineering education are supervised by a tutor. Students can get feedback on their progress and hints when in need of help from the tutor. Often the tutor will grade the laboratory work. This support is also needed when students work with a remotely controlled laboratory. We believe that live audio-video is a natural way for tutors and students to communicate over a distance. The tutor should be able to see the students' computer screen to understand the work situation. We have built a remote laboratory to teach remote maintenance and real time Java programming of embedded systems. It supports synchronous audio-video communication with the tutor. Application sharing is provided by an external tool. The laboratory is used by university students of electrical engineering and computer science. The educational concept is problem based and self-directed learning. Students work in groups of two with the experiment and write a program that controls the deflection unit of a laser system and generates a picture. They observe the generated picture and the lab devices by a user-controlled web cam. We want to make students self-directed in their learning so that they get maximum responsibility and control over their learning process. The ability to learn self-directed is an important factor for success in life long learning. In a comparative evaluation we investigate how well self-directed learning works in our remote laboratory setting. We have developed two instructional designs for the evaluation: In the self-directed setting the student group set own learning goals after some predetermined tasks. The tutor acts as E-Coach or E-Moderator. In the teacher directed setting the tasks are given and the tutor acts as E-Instructor. We are currently evaluating student motivation, task success and the consulting effort of the tutor comparing these two settings.*

Index Terms — *remote laboratory, remote programming, self-directed learning, tele- tutorial assistance*

INTRODUCTION

A major goal in engineering education is that students acquire problem solving and creativity strategies so that they become able to construct technical systems. Such strategies can be learned by working on small problems and construction assignments in a problem-based learning environment. Laboratories are a typical example of a problem based learning setting. They allow applying and testing theoretical knowledge in practical learning situations.

Reinmann-Rothmeier and Mandl propose the following guidelines for problem based learning environments which they derived from the learning theories of anchored instruction, cognitive flexibility and cognitive apprenticeship [5]:

- **Situated and authentic learning**. Letting students solve realistic problems will enable them to apply their knowledge in practical situations. Authentic problems will motivate students.
- **Learning from multiple perspectives and contexts**. Solving several related problems which all require the same basic skill will make it more likely that the skill can be applied in a different practical situation.
- **Learning in a social context.** Learning and problem solving should be done in student groups. If students have experts as models they can acquire skills, knowledge and orientation.
- **Learning with instructional support**. Complex problem solving tasks without instructional support will often demand too much from the students and will lead to ineffective learning. Many students need instructions and help for solving problems. The learning environment shall provide knowledge for solving the problem.

Because instructional support is an important element especially in a problem based learning setting, remote laboratories should provide a support for students. In typical local laboratories, students can get assistance from a local human tutor. We think, that in a remote laboratory a tele-tutor, who can communicate by synchronous communications tools with the students, should be an element of the instructional support.

INSTRUCTIONAL SUPPORT IN REMOTE LABORATORIES

The main pedagogical function of a human tutor in a local lab is to give information and assistance in questions concerning the content or referring to technical problems. He also gives feedback to motivate the students, assess the learning and acting results of the learners, organizes the learning process and set time limits.

Other tasks of a tutor in a local lab can be the technical maintenance of the lab equipment and the organization of the laboratory. Sometimes he develops the lab tasks and the documentation for the experiment.

We think that these functions of a human tutor in a local lab also need to be provided in a remote laboratory. This requires a new design of instructional support, because in a remote laboratory students and the experiment are not in one room. Three different solutions for this problem are possible:

- **Local tutor:** A tutor, who is in the same room as the students, supports the students. Only the experiment equipment is remote. The advantage of this solution is that the communication and collaboration between the tutor and the students need no extra technical equipment and bandwidth. However, money must be appropriated for the personnel costs of the tutor and in case of laboratory sharing between institutions tutors must be trained. A distributed scenario, where students from different locations work with the remote experiment, is not possible with this solution, because no communication tools are provided.
- **No synchronous tutor:** One possible solution for the instructional support in a remote lab could be to minimize the effort for the consulting by a human tutor. The students will not get any support by a human tutor during the lab session in this solution. The web based lab environment must fulfill most of the above mentioned functions of instructional support. The documentation of the lab must be very comprehensive and understandable, so that students are able to find answers and solution for their questions and problems on the web pages of the laboratory. An important advantage is that the students can work on the lab tasks when the tutor is not available. The costs are comparatively low, because no personnel budget is needed. However, a remote laboratory without any human tutor is very unrealistic. The lab equipment must be maintained sometimes. Asynchronous support via E-Mail must be provided for helping students, who can not find answers to their questions in the lab documentation. The disadvantage of the asynchronous support is that the students must accept a time delay for getting an answer to their questions. If the delay is to long, they could become demotivated.
- **Remote tutor:** A human tutor supports the students over a distance via synchronous and asynchronous communication tools. Synchronous tools like videoconferencing and application sharing allows a flexible and fast help for the students. However, the synchronous communication restricts the time flexibility of the students. Additionally bandwidth is necessary and technical equipment has to be integrated in the learning environment. Therefore, alternating asynchronous and synchronous phases can help to combine the advantages of these two communication forms. The synchronous support can be used, when the students work with the lab equipment. Upcoming problems can then be solved immediately by using videoconferencing, chat and application sharing. The amount of interactivity can be reduced during the preparation and postprocessing of the laboratory session. A web based lab environment with synchronous and asynchronous communication tools makes it possible for several students from different locations to work together on the tasks of a remote laboratory.

In the remote experiment, described below, the learners can contact a remote tutor. Videoconferencing, text chat and application sharing are provided in the web based lab environment.

THE REMOTE EXPERIMENT

We have developed a remote experiment for picture generation by laser deflection. In this experiment, students write embedded Java programs to generate laser pictures and animations.

The laser system of the experiment consists of a green 3mW laser beam, which is deflected by two mirrors of a galvanometer scanner in X- and Y-direction (figure 1 and 2). The scanner can move the beam to 30,000 positions per second. The deflection is controlled by two analogue inputs of the scanner. They are driven by DA-converters controlled by an I/O-Card in an embedded system.

The galvanometer scanner and the laser can be turned on and off by the digital outputs of the I/O-Card. An analogue input of the I/O-Card measures the voltage signal of a photosensor that is placed on the canvas. When the laser beam hits this sensor, the voltage output of the sensor increases. A window discriminator allows setting two threshold values so three different voltage areas can be distinguished by the digital inputs of the I/O-Card.

The embedded system is a PC 104 single board computer, designed to meet the needs of embedded applications requiring real-time control with web-enabled capability. On the embedded system runs a Java based real time operating system from Esmertec called "JBED". When the board is booting, it is getting a boot file from the lab server of the experiment. This file contains Java classes that are important for running the system. For example, the IO-Manager allows a comfortable control of the I/O-Card. And the Java servlet "DynamicClassHandler" allows the dynamic loading of Java bytecodes from the lab server as they are needed. Once on the embedded system, the bytecodes are compiled into native machine code by the JBED software. This ahead of time compiling ("AOT Compiling") improves the running time of Java programs compared with interpreting Java bytecode.

The embedded system uses a real time earliest deadline first scheduler. When a new task is installed, CPU time and deadline have to be provided. Jobs without real time requirements can be performed with standard Java threads.

Java Programs can be developed in a web based programming environment that is realized using Java Server Pages (JSP). The Java server page communicates with a programming server on the lab server developed with Java Beans, which in turn communicates with the "DynamicClassHandler"-Servlet.

So Java programs developed in a browser anywhere in the world can be executed with real time capabilities on the embedded system to control the I/O-Card and to generate laser pictures.

The web based programming environment (figure 3, middle part) allows editing of Java program files in the editor window. Files can be loaded and saved on the lab server with the buttons and input fields on the upper left. The upper right of the programming environment is for compiling and running Java programs. Java files are compiled on the lab server (button "compile") and compiler messages are displayed in a separate window. To start a Java method, the user asks for a list of Java methods in the file ("inspect"), chooses a method ("select"), enters actual parameters in a separate window and calls the method ("start"). If the program works correctly, the laser system will generate a picture on the canvas. A separate console output window facilitates the debugging of Java programs.

The left part of the window in figure 3 allows students remote access to the lab and is thus a substitute for being present in the lab ("telepresence"). They can select among three fixed cameras to see a live video of the canvas, the status lights of the devices or the moving galvanometer scanner and one camera ("PTZ-Cam") that allows users to pan, tilt and zoom in on details. Users can switch on and off the embedded system. A microphone transmits the sound of the operating scanner via an audio server. The users can take a snapshot of the created laser picture.

The right part of the window in figure 3 provides the possibility for different users to communicate with each other over a distance. They can communicate via audio, video and text chat after logging in with a username. The bandwidth can be adapted to the available bandwidth. The client side of the communication environment was realized with "Macromedia Flash MX". The communication server is based on the "Macromedia Flash Communication Server MX". We have chosen this software solution, because it complies with the following criteria:

- A video chat of more than two users is supported.
- The audio quality is acceptable.
- The user need not install a separate communication application. The developed communication application runs in all standard web browsers when the Flash plugin is installed.
- It allows integrating communication elements in a custom-built web page.

Application sharing is provided by an external tool. We are currently testing NetMeeting and VNC (http://realvnc.com) for this purpose. VNC is platform independent, but only allows complete desktop sharing and not to share only a certain application or browser window.

Instead of the operating mode "Programming" shown in figure 3, the user can select the modes "Manual Control" or "Dynamic Test". The software components of these modes are realized by Java applets that communicate with correspondent server applications on the embedded system (see figure 2). In the "Manual Control" operating mode the user can deflect the laser beam by two sliders or text input fields in X- and Y-direction. Furthermore the current voltage output of the photosensor and the status of the window discriminator are displayed. In the mode "Dynamic test" the users can measure the dynamic characteristic of the laser system.

We have developed a software library for vector based picture and animation generation in Java. The library eases the development of laser pictures and animations. It supports geometric transformations like translating, scaling and rotating. The library contains classes to create basic shapes like point, line, triangle, rectangle, circle, polyline and polygon. Animations consisting of different frames of laser pictures can be designed. Moreover, animations can be generated with real time properties.

THE REMOTE EXPERIMENT IN THE LABORATORY FOR PROCESS CONTROL

The remote experiment "Picture generation by laser deflection" is one of eight experiments in the laboratory for process control at the University of Hannover and is the only one where students are assisted by a remote tutor. Students learn and apply basics of process control: industrial automation systems, bus systems for process automation, programming of industrial automation systems, hardware-oriented design and remote maintenance. In the summer term 2003, twenty students of electrical engineering and computer science in the third year of their study take part in this laboratory. Students work in groups of two or three and perform one of the eight experiments every week. They have to prepare for each experiment by reading documents at home and have to solve a substantial part of each experiment to pass the lab.

The laser experiment is organized in two phases: preparation for the experiment and practical performing of the experiment. The lab preparation is supported by asynchronous communication between the tutor and the student. Laboratory documents are provided electronically and student solutions placed in a web based collaboration server. We use BSCW (Basic Support for Collaborative Work, http://www.bscw.de) for this purpose. The experiment web site includes all necessary information for the lab preparation and the lab tasks for each student group. Also students can download all documents as PDF-files for offline use. Each group has its own folder in the shared workspace, where the members of the group can upload files. During the preparation of the lab, students familiarize themselves with the documentation of the hard- and software. They complete parts of a Java program for the embedded system. In the current term we perform an educational evaluation, so we want to give students equal working conditions. That is why the student groups come to the University, where they have four hours time to perform the lab. When students have problems or questions, they can communicate and collaborate with a tutor, who is in another room, via videoconferencing and application sharing.

EVALUATION APPROACH

With our educational research we want to clarify which pedagogical role (e-moderator or e-instructor) is suitable for a remote tutor in a remote laboratory for which students and under which conditions. A tutor can guide the students more or less strict through the problem solving process in a remote laboratory. If he acts as e-moderator, the students can learn self-determined. The e-moderator stimulates the meta-cognition of the learners and advises on the choice of the learning goals and acting goals. If the tutor prefers the role as e-instructor, he controls the learning process. First of all, he acts as knowledge mediator and tries to convey his knowledge to the students.

We investigate this research question in the context of self-directed versus teacher-directed learning in a remote laboratory. Self-directed learning seeks to put the learner as much as possible in control of the learning process. The freedom of choice can refer to different dimensions like learning goals, learning place and time and learning strategy [1]. Especially for learners in continuing education a self-directed didactic concept for remote laboratories has the advantage that they can choose the learning goals and tasks according their actual needs. A teacher-directed concept could be more suitable for learners, who have less initial knowledge, because self-directed learning setting can demand to much from them.

We are performing a comparative evaluation study in the laboratory for process control described above. We are following the evaluation methodology of Borz/ Döring and distinguish independent, dependent and control variables [2]. Our main research question is: How does the degree of self control considering initial knowledge influence motivation, task success, consulting effort and communication behaviour? In addition, we will measure conditions for the type of learning motivation as control variable (figure 4).

Regarding the **degree of self-directed learning** we have implemented two different educational settings (see Table 1):

- **Self-directed**. High degree of self-direction of the students in the dimensions learning goals, tasks, problem solving process and tutor role. The tutor acts as an e-coach or e-moderator. He supports the students in learning to learn, moderates the group discussions and answers the emerging questions of the students.
- **Teacher-directed.** Low degree of self-direction in the dimensions learning goals, tasks, problem solving process and tutor role. The tutor acts as an e-instructor: He explains the tasks, guides the group in the learning process along the structure of the subject rather than the actual task (i.e. subject-oriented) and answers the questions in a subject-oriented way.

In the teacher directed setting, students complete parts of a Java program for the embedded system during the lab preparation. The students need this program for the practical performing of the laboratory. While working with the experiment they work on four tasks: First they get to know the hard- and software by starting different Java methods, that already exists und that generates pictures. In the second task, they measure the dynamic characteristic of the laser system. The results from this task are helpful for the solution of the next task: The students develop a real time Java program for finding the X- and Y-position of the photosensor. The problem solving process for this task is described in detail and the tutor gives the students subject oriented hints. In the last task the students create a laser picture by using the laser graphic library. In this setting , the tutor acts as e-instructor, and might for example explain the theory of real time programming. Students have to contact the tutor after finishing certain parts of the tasks.

The self-directed setting gives the students more freedom of choice, as they can set own learning goals. They have the choice between a focus on real time programming (finding the coordinates of the photosensor) or a focus on object oriented programming in Java (generating laser pictures by using the laser graphic library). The lab documents are not specific, but describe the tasks only broadly, so students can put the tasks in concrete terms. The tutor acts as e-moderator, he supports the students in learning to learn. For example, when the students have questions, the tutor gives them hints, where they can find an appropriate answer to their questions in the documentation.

We have defined the dependent and control variables in the following way: With communication behavior we describe the media, which are really used by the students during the experiment. The consulting effort is the time effort of the tutor for the support of the students. We will differentiate between the support for technical questions, questions concerning the content, learning process and moderation of the collaborative work. The task success is evaluated by the tutor. He assesses the results (e.g.: laser picture, Java program) of the group by comparing the results with other groups and with the pre-determined goals. We distinguish six different types of motivation: amotivated, extrinsic, introjected, identified, intrinsic and interested motivation. The relevant conditions of motivation, which we will measure, are perceived content relevance, instruction quality, social relatedness, support for competence and support for autonomy. This classification of learning motivation types and relevant conditions of motivation is based on the Self Determination Theory (SDT) from Deci, Ryan [3] and the motivation theory from Prenzel et al. [4]. The initial knowledge is measured with a questionnaire before the experiment, because we think, that it is an important factor in a self-directed learning setting. For example, students, who only have little knowledge of Java programming, will have problems with self-directed learning and need special support of the tutor. Students with experience in programming will be able to work mostly independently.

We use qualitative and quantitative methods for the acquisition of the necessary data. In a pretest we ask for the initial knowledge relating to the soft- and hardware of the laser experiment and the programming experience in Java. After the lab students answer questions on the technical quality and the acceptance of the tele-tutorial assistance. For the measurement of the different types of motivation and the relevant conditions of the learning motivation types we use a validated questionnaire developed by Prenzel [4]. During the lab session the tutor is taking notes about the consulting effort and the communication behavior. This is complemented by logging communication for classifying it after the lab session.

Right now we are performing the evaluation with eight groups of students. The first impression is that students are interested in the lab tasks and that they value tele-tutorial assistance as helpful. Application sharing proved to be of critical importance for the tele-tutor to understand students and to assist them in solving the tasks.

CONCLUSION AND OUTLOOK

Our educational evaluation will be completed in the summer of 2003. It will give insight to the educational value of self-directed learning with tele-tutorial assistance in a remote laboratory.

In our current laboratory, we focus on synchronous communication between a remote tutor and students during the lab session. When remote laboratories are used on an international scale, asynchronous communication will be needed more than to date. Tutors will assign tasks to students, support them in lab preparation and grade lab reports using asynchronous communication. Also organizational questions have to be solved and business models established for usage of remote labs on an international scale. So further research is needed to clarify these questions.

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FIGURES AND TABLES

FIGURE 1
LASER EXPERIMENT COMPONENTS

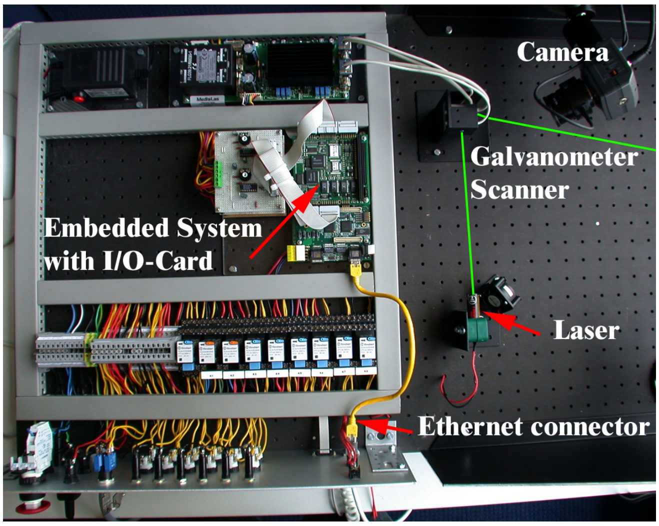

FIGURE 2
Block diagram laser experiment

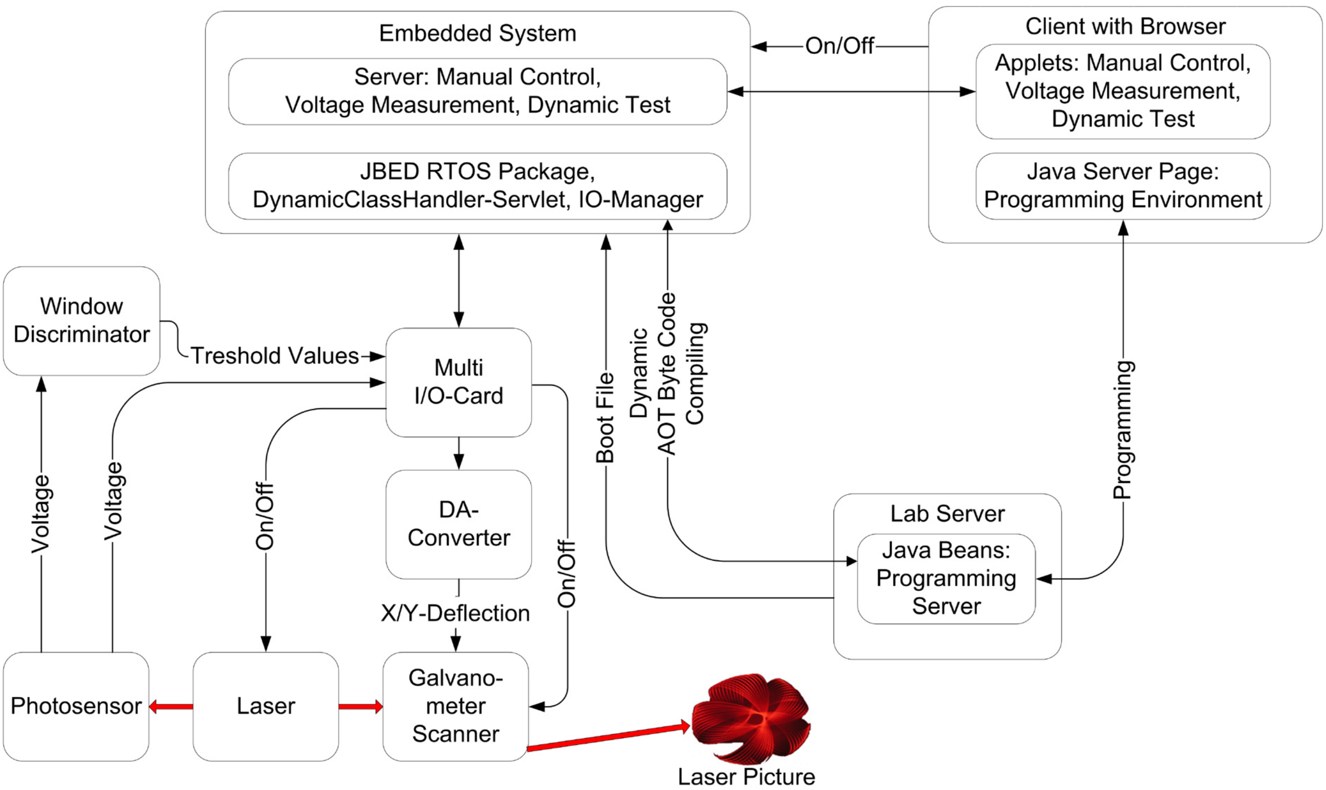

FIGURE 3
WEB BASED LAB ENVIRONMENT

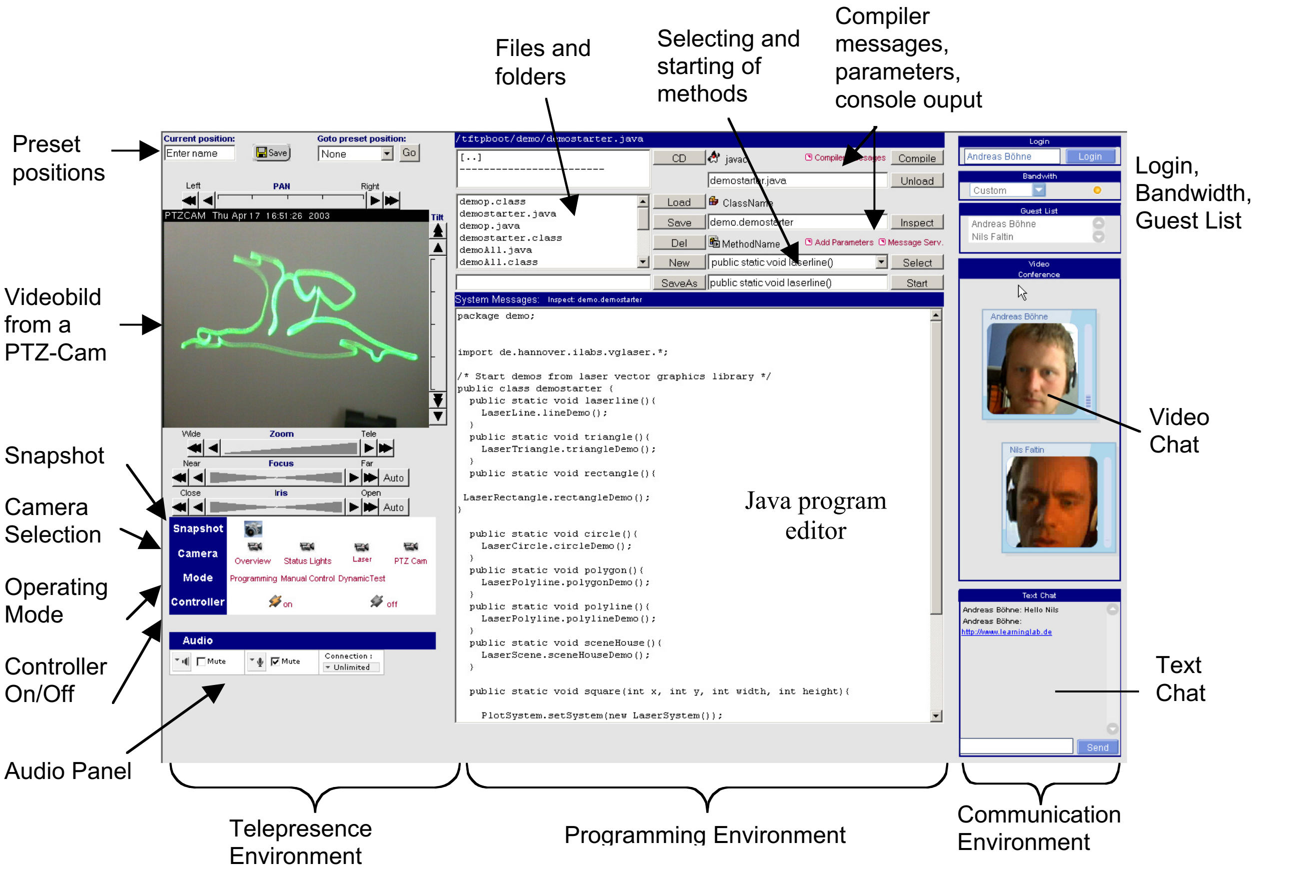

FIGURE 4
VARIABLES OF THE RESEARCH QUESTION

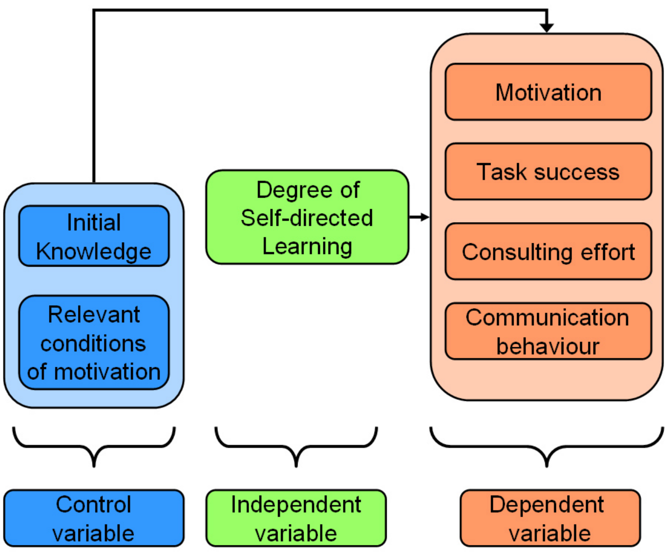

TABLE 1
DEGREES OF SELF-DIRECTED LEARNING

	Self-directed setting	**Teacher-directed setting**
Learning goals and tasks	After a pre-determined task, the group develops the learning goals and tasks. The tutor approves goals and tasks.	Predetermined tasks with increasing difficulty
Problem solving process	directed problem solving process	undirected problem solving process
Role of the tutor	e-coach, e-moderator	e-instructor