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Distributed group work in a remote programming laboratory—a comparative study*

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The study compares pairs of computer science and engineering students working distributed over several rooms with pairs collocated in one room. The task was to control and program a remotely located laser display device. In each case they were supported by a remote tutor. Distributed persons communicated over video conferencing, text chat and desktop sharing. Statistically significant correlations were found between initial knowledge and task performance (r = 0.581, p = 0.019). Setting alone was not statistically significant, but became significant when eliminating initial knowledge in a partial correlation (r = 0.524, p = 0.040).

Keywords: Collaborative learning; CSCL; evaluation; remote laboratory; programming laboratory.

INTRODUCTION

WORKING WITH real devices or realistic device models is an important part of engineering and technical education. It allows students to apply their theoretical knowledge in a practical situation and to adopt new skills within a realistic problem-solving environment.

Remotely controlled experiments provide students such learning experiences over the Internet, principally independent from time and place [1]. Several educational institutions can share remote experiments and thus provide more experiments or reduce the cost per experiment because they are better utilized than if each institution would provide just a few local experiments. Especially off-campus and part-time students benefit from the flexibility to perform experiments from home without the need to travel to a local laboratory.

In general, small groups of students work on predefined assignments in laboratory sessions. This allows them to share their expertise and ideas to solve the often complex measurement, construction or programming tasks. When they need help, they can usually call for a tutor or teaching assistant to support them. In a local laboratory, this is easy, as fellow students and the tutor are collocated in the same room and can communicate face-to-face. But when place flexibility is needed, as for off-campus students, where all persons are geographically distributed over several locations, this communication has to be computer-mediated. Communication should be synchronous to allow instant support and problem solving with communication media like text chat, video conferencing and application sharing.

In a previous study we showed that remote support by a tutor worked very well, with audio and application sharing being used and valued most [2] (Fig. 1). But it was not clear, if this positive result would be transferable to the cooperation within a distributed student group. Students usually spend much more time communicating within the group than communicating with the tutor. Also cooperation is much more symmetric, while communication with a tutor is largely asymmetric with the tutor providing hints and feedback. This is why we set up a comparative evaluation of distributed versus collocated group work with a remotely controlled experiment.

RELATED WORK AND STUDY HYPOTHESES

Evaluation of local and remote access modes to laboratories

The type of laboratory can have an influence on learning outcomes. A study at the University of Melbourne, Australia compared the impact of access mode (local, remote, and simulated) on the achievement of eight learning objectives in an undergraduate mechatronics engineering laboratory [3]. Analyzing the laboratory reports of 118 students, statistically significant differences were found in four objectives. For example students in remote and simulated groups outperformed students in local access mode for the objective 'exception handling' with an effect size of 0.80 SD (remote) and 0.88 SD (simulated). Simulation was inferior to local access mode in objective

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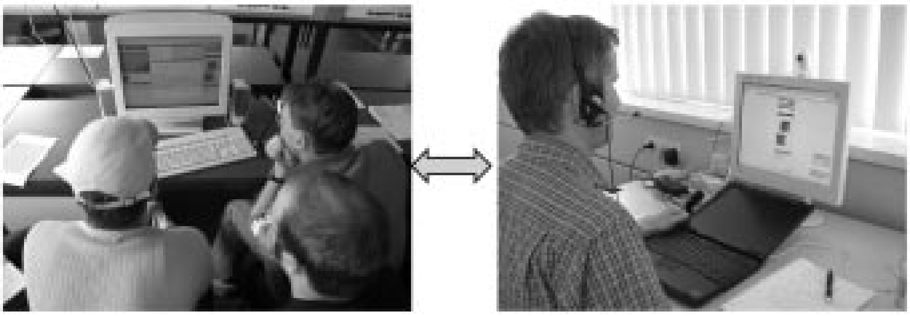

Fig. 1a. Tele-tutorial support in the previous study.

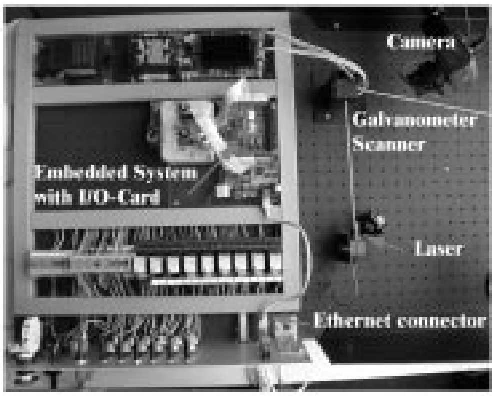

Fig. 1b. Laser display hardware.

'limitation of accuracy' by 0.64 SD, with remote mode being very similar to local mode. The aggregated effect across objectives was not reported, but can be approximated by calculating the mean from the published data as 0.26 SD (remote—local, remote is better) and –0.10 SD (simulated—local, local is better).

The study of Ogot, Elliot and Glumac [4] compared remote and local access to a fluid mechanics laboratory. No statistically significant differences were found between marks obtained in both conditions. Significant differences were found between sub-groups of the remote access condition that did or did not have an extra hour to do the prelab exercises. However, only the total scores of seven different sections were compared ignoring possible differences between conditions in single sections. In addition, only the local mode was supervised by a laboratory demonstrator.

In a study with 44 participants working in groups of two, Tuttas, Rütters & Wagner [5] compared remote and local access to a process control laboratory. No statistically significant differences between both conditions were found in knowledge gain, as measured with a pre-test and a post-test. Working time for one of the tasks was significantly higher in the remote condition, where the machine was scanned with a Pan-Tilt-Zoom Camera.

Evaluation of distributed group work

The study on distributed group work in a remotely controlled experiment is related to research in the areas of computer-supported collaborative learning (CSCL), computer-supported cooperative work (CSCW) and computer mediated communication (CMC).

A general conclusion from research on distributed team work is that problem-solving processes, where information is discussed and transformed, are best supported by synchronous communication tools [6]. In contrast, asynchronous communication tools are best suited for information gathering. Because problem-solving processes are at the center of a remotely controlled experiment, we provided participants with the synchronous communication media text chat, video conferencing and desktop sharing.

Results of CSCW and CSCL research regarding the effect of computer-mediated communication on group work performance are inconsistent. Some studies emphasize the missing social clues ([7, 8, 9]). In study [7], computer-mediated communication groups needed longer to reach consensus. This is in contrast to Sonnenwald, et. al., who found no statistically significant difference between groups working collocated or distributed on scientific data analysis tasks [10]. The effect of computer-mediated communication on learning outcomes seems to depend on many factors like group size, group composition, task type and communication media [11].

Study hypotheses

Computer-mediated communication is more difficult than face-to-face communication because of missing social cues. However, based on the results of the Sonnenwald study and our own experiences with tele-tutorial support in a previous study, we still expected that groups would be able to cooperate successfully with audio communication and desktop sharing in our study. Also it is well known from learning research, that initial knowledge has a strong influence on learning results [12]. This led us to the following hypotheses for our study:

1. Student groups working in the distributed setting will report more difficulties with cooperation than collocated groups.
2. Task success, motivation and consulting effort will be similar in both settings.
3. Initial knowledge will have a larger influence on task solving than the setting.

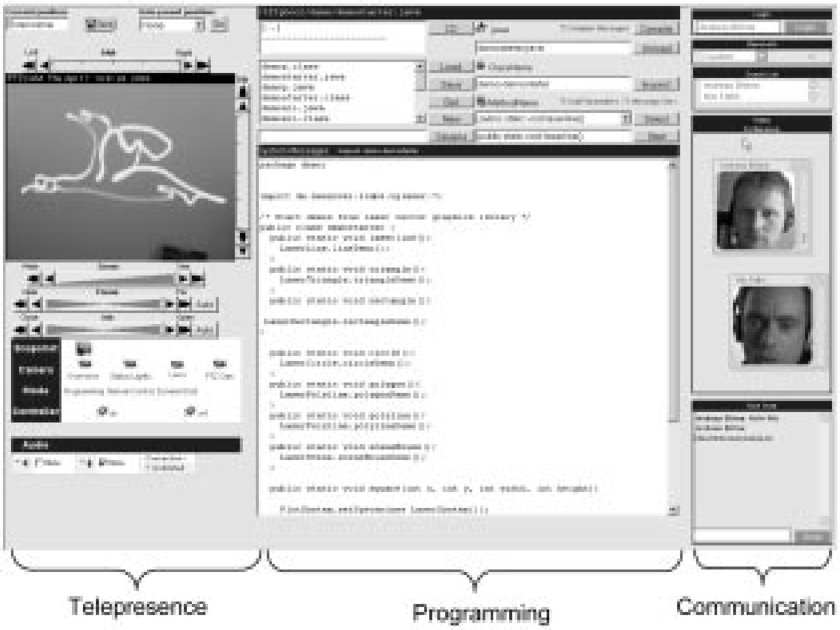

Fig. 2. Web-based experiment environment for laser display experiment.

THE REMOTELY CONTROLLED EXPERIMENT

In the evaluation, students worked with the remotely controlled experiment 'Laser Display' (Fig. 2 and reference [13]). It provides a web-based editor for Java programs that are then executed on an embedded system. The program controls a laser and a deflection unit, so that line graphics and animations can be drawn on a canvas. These graphics and animations are transmitted via a video camera and the Internet back to the programming student. The web-based experiment environment consists of:

- *telepresence environment* providing live video streams of the experiment from four locations and one audio stream;
- *programming environment,* to edit, compile and run Java programs, and
- *communication environment* providing audio, video and text chat transmission from all participants.

It was combined with an external tool (NetMeeting) for desktop sharing.

STUDY DESIGN

To determine the effect of distributed group work in the specific context of remotely controlled

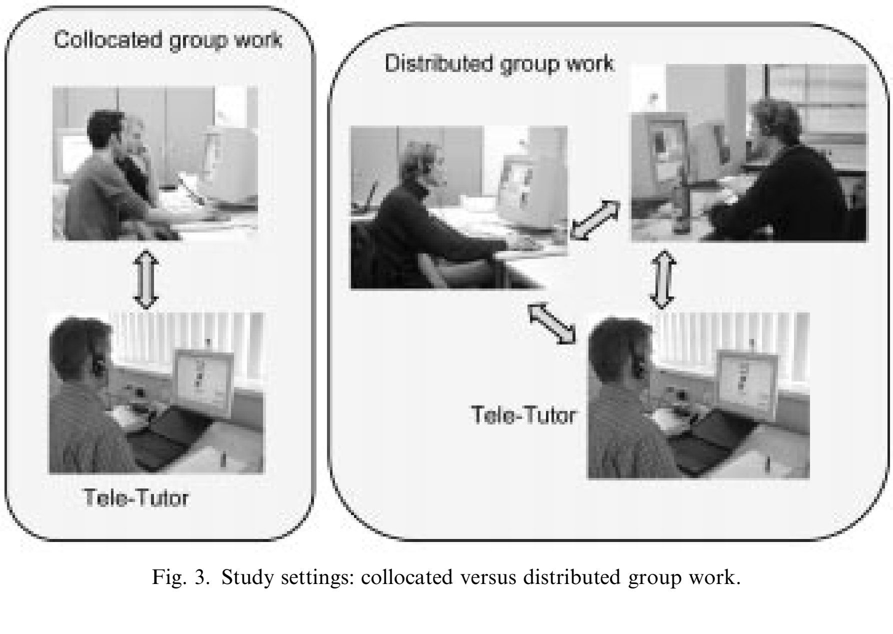

Fig. 3. Study settings: collocated versus distributed group work.

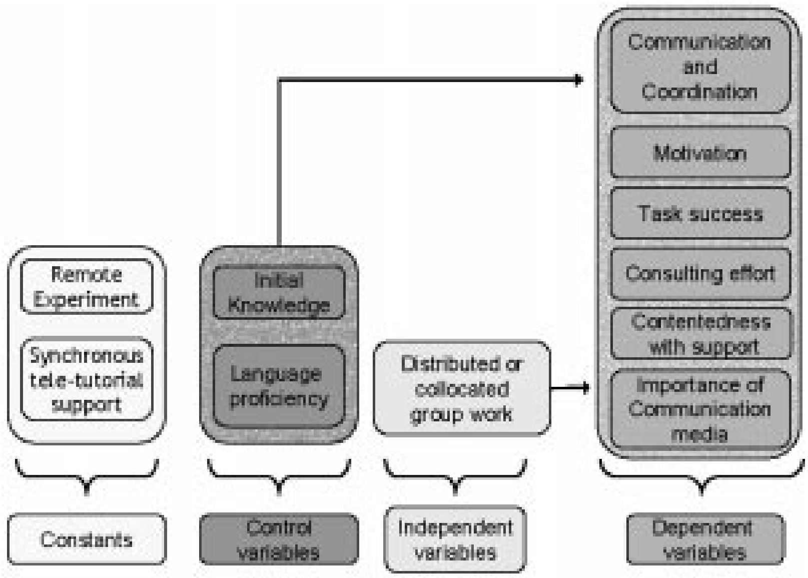

Fig. 4. Variables in the study.

experiments, we performed a comparative evaluation. It compared the learning process and the learning results of distributed groups with groups cooperating locally (see Fig. 3). In both cases, students were supported by a tele-tutor. Students and tutor could communicate with the synchronous communication tools video conferencing, desktop sharing and text chat.

In both settings, students had the same task assignments and were assisted by the same tele-tutor, so these are constant factors in the study. Dependent variables measured in the study were: task success, motivation, importance of communication media, contentedness (satisfaction) with support and consulting effort (Fig. 4). Also, quality aspects of communication and coordination of task solving were determined. The dependent variables are not only influenced by the setting, but also by the students' initial knowledge and language proficiency. They are included as control variables in the study to determine and compare their effect sizes. Furthermore, this allows a better determination of the true influence of the setting on learning. Control and dependent variables are described in more detail below.

Participants

Study participants were students from the University of Hannover, Germany. They attained the course 'Programming II: Introduction to programming in Java' in the winter term 2003/2004. Main subjects in the course were:

- Java language elements;
- basics of object-oriented programming;
- simple abstract data types;
- graphics output;
- programming graphical user interfaces;
- file I/O;
- threads;
- applets.

There were 10 regular homework assignments for this course. Students providing at least five correct solutions obtained a bonus in the end of semester test. An extra assignment was offered this term: participating in the research study covering a laboratory programming session with the remote experiment 'picture generation with a laser display'. Study participants were informed of this opportunity during the lecture, and participation can thus be seen as voluntary. Many students (31 groups of two persons) expressed their interest to participate, 22 groups accepted a date but only 15 groups showed up. Two of them participated in a pilot study, so 13 groups participated in the main study. To account for potential language proficiency problems, foreign student groups were distributed evenly over both settings. Apart from this restriction groups were randomly assigned to the distributed setting (7 groups) and the collocated setting (6 groups).

One group was formed by the research team whereas all other groups had formed themselves and applied together, so one can assume that students in a group knew each other.

Students were between 20 and 28 years old (mean: 22.8), 3 female and 23 male. Their study major was in electrical engineering (8), computer science (13) and engineering economics (4). The curriculum suggests students to take the course in their first term and this was the case for 11 students. Several were from the third term (4), fifth term (8) and even the seventh term (1).

A substantial number of foreign students, mostly from China, participated in the study. The tutor noticed that many of them had problems to communicate in German or English, so he took notes about their language proficiency. As no formal test was used and the observed proficiency was either sufficient or problematic, a dichotomous variable was used to represent it. There

Table 1. Task duration and points

Task part	Description	Duration (min)	Points
1	Start Java methods to generate animations. Watch animations with video cameras.	15	0
2	Measure speed of laser deflection.	15	10
3a	Develop program to draw a static scene of geometric objects.	40	25
3b	Animate the scene by rotating and enlarging it.	20	15
4a	Extend the graphics library with the new class 'LaserCharacter'.	45	25
4b	Extend the graphics library with the new class „LaserString'.	45	25

were no mixed groups; either both members had high or low language proficiency, so it is now recorded as a group variable, with 5 out of 13 groups classified as low language proficiency (see Table 2).

Laboratory session time line

One week in advance, students received an email with instructions on how to prepare for the laboratory session. They should spend one hour reading the web-based documentation to learn about the hardware and software of the experiment and to prepare the program source code for task 3a.

The laboratory session took place in dedicated rooms at the University of Hannover for a total of four hours. Students were welcomed and introduced to the web-based experiment environment (10 minutes). For students working distributed, this included the desktop sharing program. Then they answered the entry questionnaire (15 min). For working on the task assignments, students had 180 minutes time and the tele-tutor was available constantly to assist them during this time. The session closed with the exit questionnaire (25 min) and an interview (10 min).

Tasks

Main learning subjects in the laboratory session were remote control, remote maintenance and object-oriented programming of graphics and animations. Programming of graphics was chosen after consulting the lecturer of the course 'Introduction to programming in Java', because it fits well with the subjects of the course. At the time of the study, in mid term, students had acquired some basic knowledge in Java programming. But the lecturer informed us that students in general had difficulties to understand advanced object-oriented programming concepts.

In the laboratory session, students worked on four tasks (Table 1). The tutor rated quality of the task solutions provided by the students. The maximum number of points achievable for each task is given in the table. Task one only served to introduce the web-based learning environment, so it was not rated. Also, the expected working time for each task is given. Only for the first two tasks these times were enforced, as they are of a more simple and introductory nature.

In the first task, students got to know the web-based learning environment by starting Java methods and watching animations with video cameras. The second task introduced the coordinate system and allowed measuring the speed of the laser deflection by a series of test drawings. Both tasks were of an introductory style and gave students the opportunity to practice remote control and remote maintenance.

In the third task, students programmed line graphics and animations in Java, starting from an example program. In task 3a, students developed a program that draws a simple graphics scene, consisting of a square, a triangle and a circle. Students prepared the program source file at home, but debugging and completing it was done during the session. In task 3b this program was extended to display an animation of the rotating and expanding scene. Students could use the example program as a basis for their programming, but also had to look up some Java methods in the graphics library documentation. This task is of medium difficulty, as the structure of the example program can be reused, so only a simple transfer of knowledge is needed.

The fourth task was more demanding, as there were no hints given how to proceed and there was no example solution for a similar problem. In addition, more advanced object-oriented programming concepts had to be understood and applied to extend a graphical programming library. Students should add classes to display characters and character strings as line drawings. They were provided with a skeleton (incomplete) program source code for these two Java classes. Still, students had to understand how these classes relate to the existing programming library through inheritance of Java methods and they had to add program code that would perform the line drawing.

Perspectives from CSCW and CSCL research

Theories from CSCW and CSCL research provide classification of tasks and can aid in selecting appropriate communication media. Two theories are used here to classify the tasks in the study.

Grath ([14], see also [8]) defines eight types of cooperative tasks. The tasks in this study mainly belong to the category 'intellective tasks: solving problems with a correct answer'. Students perform complete actions in the study with planning, decision and execution processes. The execution processes include operating the graphical user interface of an Applet in task 2 and editing program source code in tasks 3 to 4. These are classified as 'performances/ psychomotor tasks'.

The 'Media Synchronicity Theory' [6] classifies tasks by the communication processes needed to solve them. It defines *conveyance* as the process of gathering information and *convergence* as the development of a joint understanding regarding certain information. Both processes are relevant for the study tasks. In tasks 3 to 4 students need to gather information about methods available in the laser graphics programming library (conveyance). But to solve the tasks, students also need to reach a consensus on how to proceed (convergence). The experience from this and previous studies is that students in a programming laboratory do not have a phase of conveyance followed by a phase of convergence but instead interweave both processes. Students tend to solve programming tasks in small steps, following a 'trial and error' approach.

Data collection and analysis

At the beginning of the laboratory session, students filled in an online questionnaire. It covered the following areas:

- biographical data (age, sex, major, study duration);
- duration of preparation for laboratory session;
- experience in programming (self assessment);
- initial knowledge.

The Initial Knowledge test was a multiple choice test, with four questions on the remote experiment and six questions on Java programming. All questions received equal weight in the analysis, so the number of correct answers was used as an indicator for initial knowledge. For student groups, the average of the two students' scores was used as the indicator. It was stronger correlated to task success than the maximum of the two scores.

During the laboratory session the tutor wrote a protocol of the consulting. For each task part, he noted the duration of consulting, number of relevant hints given and the student working time. To prepare for a detailed analysis of student problem solving strategy, communication between persons and the contents of one student computer screen were also recorded.

As only few groups managed to reach task 4, to prevent a ceiling effect, only tasks 1 to 3 were used to calculate task success.

As described above, the tutor rated the students' solutions regarding their completeness and correctness, assigning *raw points* to each task (Table 1). The number of *relevant hints* given was subtracted, to compensate for the advantage students had from a hint. This gave a net point, or *quality of problem solving* for each group. By dividing it by students working time they spent on the tasks, the *efficiency of problem solving* was calculated. This was scaled to a percentage value using the total *available time* and the maximum *achievable points*. Solving all tasks completely in the maximum available time would result in a value of 100. This reflects that it is better, if more work is done in the same time or less time is needed for the same amount of work.

Efficiency of problem solving

$$\frac{\text{raw point} - \text{hints given}}{\text{working time}} \times \frac{\text{available time}}{\text{achievable points}} \times 100$$

From a theoretical point of view, the *efficiency of problem solving* is a better indicator for *task success* than *raw points* or *quality of problems solving*, as it takes most solution attributes into account. This was confirmed in the statistical analysis, where it also had the strongest correlation with the independent variables of the study (language proficiency, initial knowledge, setting).

At the end of the laboratory session, students filled in an online exit questionnaire. It included student views in the following areas:

- Cooperative problem solving and individual learning success.
- Importance of communication media and their technical quality.
- Contentedness with tele-tutorial support.
- Quality aspects of communication and coordination.
- Roles of cooperation partners.
- Motivation and relevant conditions for motivation.

Students rated the importance of the communication media text chat, audio, video and desktop sharing and the technical quality of the communication media. Contentedness with tele-tutorial support included the questions on how easy it was to contact the tutor, how clear and comprehensible his hints were and whether a local tutor would be preferred.

The different kinds of motivational regulations were measured with a questionnaire developed by Prenzel [15], who in turn based it on the Self Determination Theory of motivation [16]. Relevant conditions to promote motivation are support for competence, autonomy and social relatedness.

Quality aspects of communication and coordination include:

- task related attributes (contribution and consensus);
- coordination attributes (ease of communication, integration of contributions);
- availability of social cues;
- socio-emotional aspects.

This part was based on a questionnaire developed by Dittler [9], with some adaptations in the parts 'social cues' and 'technical quality of communication media'.

Table 2. Influencing factors and task success per group

Setting collocated	Language proficiency	Initial knowledge (maximum =10 points)	Working time (schedule: 90 min)	Raw points (maximum: 50 points)	Hints given	Task success (Efficiency in %)
1	1	2.5	125	36	8	51.8
1	0	2.5	180	13	12	13.0
1	1	5.5	148	46	2	55.9
1	0	5.5	177	29	14	29.5
1	1	5.0	100	44	2	79.2
1	1	9.0	85	49	1	103.8
0	0	5.0	180	29	11	29.0
0	1	6.5	170	35	8	37.1
0	1	5.0	130	43	5	59.5
0	0	5.0	176	32	15	32.7
0	0	6.0	172	25	18	26.2
0	1	5.5	175	30	15	30.9
0	1	7.5	88	36	8	73.6

In a semi-structured interview, students were asked for their experience with the laboratory session. Question areas included task difficulty, relationship and cooperation of students, communication and discussion style, coordination of work, communication media and authenticity.

RESULTS AND DISCUSSION

Initial knowledge

Students prepared for the laboratory session at home. They were told that this would typically take one hour time, but they needed 1.8 hours on average according to the entry questionnaire.

The initial knowledge in experiment setup and Java programming was assessed with a multiple choice test with 10 items. Students scored 5.4 (SD 1.9) out of 10 points on average.

When asked about their Java knowledge most students responded they knew simple procedural concepts like FOR-loops (22 answers) whereas much fewer were confident in higher level object-oriented concepts like overloading of methods (10 answers). Most students (20) said they had written own programs during the course, but for almost half of the students (10) it was the first time they learned a programming language.

It can be summarized that students on average had prepared for the laboratory session and had some basic knowledge in Java programming, but were not fluent in programming nor were they well prepared for complex programming tasks involving higher level object-oriented concepts.

Task success

Task success was analysed on a per group basis, as two students jointly worked on the tasks. As described above, language proficiency and initial knowledge were also made available as group variables. Table 2 lists for each student group the influencing factors and their task success. Setting is coded 1 for collocated and 0 for distributed. Groups with sufficient language proficiency are coded 1. Task success is calculated from working time, raw points and hints given are described below. As explained there, the total values for tasks 1–3 were used.

The main research question is which influence, the distributed versus collocated setting, has on task success. This was investigated with Pearson correlations between the setting, coded as 0 for distributed and 1 for collocated and the task performance. However, taken alone, the setting did not have a statistically significant influence on learning (Pearson correlation $r = 0.286$, one sided significance $p = 0.171$).

It is known from learning research, that *initial knowledge* has a strong influence on task success and learning outcomes. This was also true in this case ($r = 0.581$, $p = 0.019$), where it was statistically significant.

Also *language proficiency* obviously has an influence on task success, as it determines how well instructional documents, and the experiment user interface are understood and also how well students can communicate with the tutor and thus explain their problems and understand hints towards solution. It turned out to be a strong

Table 3. Quality aspects of communication and coordination; ($n_{distributed} = 14$, $n_{collocated} = 12$, scale: 1 = does not apply, 4 = does apply completely: two-sided significance)

	Distributed		Collocated		t-test	
	M	SD	M	SD	T	p
Availability of social cues	2.63	0.47	3.06	0.42	2.426	0.023
Coordination of communication	2.94	0.65	3.32	0.46	1.698	0.102
Coordination of task solving	3.27	0.47	3.15	0.42	0.686	0.499

factor in this study ($r = 0.694$, $p = 0.004$) and statistically highly significant.

Using a partial correlation, the influence of language proficiency was eliminated numerically. This only raised the (partial) correlation between setting and task success a little ($r = 0.305$, $p = 0.167$) and slightly reduced the correlation between initial knowledge and task success ($r = 0.548$, $p = 0.033$).

However, reducing the influence of initial knowledge by a partial correlation between setting and task success did raise the correlation factor a lot ($r = 0.534$, $p = 0.037$) and yields a statistically significant correlation. When both initial knowledge and language proficiency were eliminated, the correlation between setting and task success rises only a little bit more ($r = 0.568$, $p = 0.034$).

Using a linear regression, the influence of each of the three independent variables on task success was determined and expressed by the standardized beta coefficients and the significance value. The resulting model had an adjusted fit of $R^2 = 0.672$ and confirmed the correlation analysis results that language proficiency (beta = 0.508, $p = 0.018$) and initial knowledge (beta = 0.515, $p = 0.019$) had a much stronger influence than setting (beta = 0.357, $p = 0.068$) on task success.

Quality aspects of communication and coordination

Students rated aspects of the quality of the communication and coordination within their group on the exit questionnaire on a scale of 1 (does not apply) to 4 (does apply completely).

Social clues are non-verbal signals like facial expressions people send during communication to indicate whether they understood their partners' communication. They also relate to knowing whether the partner is busy and where the partner points to. Students clearly had fewer social clues in the distributed setting than in the collocated (Table 3). This difference is statistically significant. It was expected to show up, as a small video image of head and shoulders of the partner makes it much more difficult to grasp facial expressions. Also it is more difficult to see what the partner is doing at the moment. Pointing to a screen location is also somewhat more difficult with the mouse than with the finger.

Coordination of communication is a measure for the ease of communication, how well students felt their partner understood them and vice versa. The need to repeat sentences is, for example, a counter-indication.

Coordination of task solving is a measure for how well the partners integrated work contributions of each partner into the common work. This includes the speed of work, contributions being taken seriously and the ease of coordination. There is a trend that coordination of communication was more difficult in the distributed setting, although it is not statistically significant (Table 3). But this did not impede coordination of task solving, which worked similarly well in both settings.

The statistical findings were confirmed by student statements in the interviews after the laboratory session. Student groups, which had worked separately, reported that there was time delay in desktop sharing that hindered the cooperation.

> *'One did not see in real time, what the other one was doing.'*
> *'Yes, the coordination could be improved. If the desktop sharing would be synchronous, the cooperation would work well.'*

But still students said that desktop sharing was important and that they were able to cooperate in an effective way over the internet:

> *'That we can hear each other is very helpful. And I liked it, that one can see what the other one is doing [. . .] and that one can point with the mouse to it.'*
> *'I see no problem in working together this way over the Internet.'*

CONCLUSION

The main research question was the effect of student group distribution on task success. Student groups working in the distributed rather than the collocated setting had a somewhat lower task success. But this effect is smaller than the effects of initial knowledge and language proficiency. In addition, it only becomes statistically significant in a partial correlation eliminating the influence of initial knowledge. This study outcome can be seen as an indication that distributed remotely controlled laboratories are an educationally sound alternative to collocated laboratories. Students can benefit from the increased flexibility in time and location without major losses in the quality of the educational experience.

More research with different student groups and learning content are needed to reach a higher external validity of these findings. Also the internal validity, especially the accuracy of effect sizes and correlations can be improved by incorporating more students as study participants.

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