Using and Evaluating Remote Labs in Transnational Online Courses for Mechanical Engineering Students

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Forming in Ankara. His research interests are metal forming technologies as bulk metal forming, sheet metal forming, bending and high speed forming, as also the modeling of metal forming processes and material characterization. In recognition of his contributions in the field of metal forming he was awarded the honorary degree Doktor-Ingenieur Ehren halber (Dr.-Ing. E.h.) by the Faculty of Engineering of Friedrich-Alexander-Universität in Erlangen-Nürnberg in 2012. In October 2014 he was awarded the International Prize for Research & Development in Precision Forging of the Japanese Society of Technology of Plasticity for process innovation, process characterization and international Leadership. A. Erman Tekkaya is member of numerous national and international committees and cherishes memberships to national and international scientific academies and associations. A. Erman Tekkaya is “Editor-in-Chief” of the Journal of Materials Processing Technology of Elsevier for 9 years.
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Abstract—Integrating online remote laboratories is still a growing field in the area of manufacturing technology and in engineering education research. In order to improve engineering education in manufacturing technology the authors developed a complex remote laboratory that can be used in this professional context to perform several important experiments at a distance. One of these experiments is the tensile test to determine material properties. As this remote laboratory is applied to more and more educational settings a sound evaluation process comes into focus. Therefore a holistic evaluation model has been developed. This model considers the individual learner’s, the technical and the didactical perspective. It mainly uses online questionnaires and relies on self-evaluation by the students. These questionnaires were applied for the first time in context of a 4-weeks online course in summer 2015. In that year 16 Students from all over the world participated in this course online, connected via Internet. During the course they had to work together in transnational teams. Among other tasks they had to use the remote lab in order to perform several tensile tests and analyze the data. Applying the questionnaires helped to understand the students’ thoughts on the experimentation process and the remote laboratory. The evaluation results show, that the students appreciate the given opportunity to perform online experimentation and they experienced an individual competence development. The paper describes the remote laboratory, the online course, the evaluation model, and the obtained evaluation results.

Introduction

Integrating online remote laboratories is not a completely new phenomenon but still a growing field in engineering education and in engineering education research\(^1,2\). Especially in the area of manufacturing technology the laboratory equipment (e.g. for determining material properties) often consists of heavy and expensive equipment. Hence, it is a challenging task to develop the necessary additional tools for remotely conducting the experiments procedures (e.g. for automatic specimen handling) and to provide experimentation for online usage. However, over the last years the authors’ institutions developed a laboratory environment for online forming technology experimentation. Within this environment students are enabled to do a tensile stress-strain experiment with their own personal computer using online technology. The main objective in this context is not only to improve the level of usability of this learning experience but also to open up the integration of laboratory learning to totally new learning settings.

The remote lab’s integration into new educational settings is accompanied by a new demand for formative evaluation in order to assess and improve the setting as a whole. Therefore, after a short literature review this paper will focus on four different aspects:

1. The developed remote laboratory equipment
Developing distance education programs in engineering education is not a very new effort. Zalewski mentions that the first attempts to access lab experiments remotely date back to 1991. In 1999 Alexander and Smelser presented an online material laboratory course making use of a tensile test simulation from the Integrated Teaching and Learning Laboratory at the University of Colorado at Boulder. Nevertheless the development of online laboratories, which are based on real physically existing and remotely controlled equipment instead of simulations, remains a particularly challenging task. Following Schaefer et al. the main advantages of remote experimentation include performing hands-on learning experiences and at the same time reaching those students, who are not able to attend on-site laboratory sessions. Here, in particular, we emphasize the latter aspect, as our example shows a case of application wherewith students who are spread all over the world are enabled to experiment together. Furthermore, Schaefer et al. recognized the necessity for expanding the number of remote laboratories. Hence, they worked out a framework for their development. The framework considers aspects like the laboratory setup, technical requirements, student preparation, implementation, and pedagogical considerations. In their work Schaefer et al. present a remotely controlled tensile test as an example for a complex laboratory. Even though the students were already able to do the experimentation online, an on-site lab assistant was still needed to handle the specimens in this example. In 2009 the authors saw robotic control of remote labs as the next important step regarding evolution in remote laboratory environments. In the meantime, this stage of development concerning remotely controlled experiments has been accomplished as we can demonstrate with this paper. Furthermore, Goeser et al. developed and presented a tensile test simulation called “The Virtual Tensile Testing Machine (VTTL)”. The authors created a detailed 3D CAD model of a real testing machine and additionally created models of five sample specimens of different materials frequently used in industry. Through a graphical interface the students could use the simulation and perform tensile tests. The student’s feedback showed mainly positive results. For example, the students reported that the usage of such simulation in course contexts helps to understand the theoretical background of material properties’ determination.

However, the necessity for establishing high quality remote labs in undergraduate education can’t be denied and the number of attempts to develop showcase projects is still growing. Publications by Azad, Auer and Harward as well as by García-Zubía and Alves provide an overview on the recent developments. Despite of all these examples it seems to be the case, that there is a larger community working on remote labs in electrical engineering than in manufacturing technology. Moreover, the evaluation of remote laboratories used in education is often very basic and does not go beyond questions like “Did you like the lab?” or “Do you think the lab helped you to understand the theoretical basics better?”. Therefore we tried to develop a holistic model and split up the evaluation into three different perspectives. We hope to both inspire the communities’ discussion and push ahead the development of remote labs in manufacturing technology with our approach presented in the following.

The remote laboratory and experimentation environment

As explained in the introduction, the discussed laboratory is a remote lab consisting of a so-called tele-operative testing cell for material characterization in the field of forming technology. The environment’s initial development goes back to the international research
project called “PeTEX – Platform for e-learning and Tele-operative Experimentation”. Within this project essential research in using remote laboratories in teaching manufacturing technology had been carried out (see e.g. Terkowsky et al. (2010), Terkowsky et al. (2011), and Terkowsky et al. (2013)). The laboratory now has been further developed in context of the research project “ELLI - Excellent Teaching and Learning in Engineering Science”. Researchers and experts in mechanical engineering and computer science from the Institute of Forming Technology and Lightweight Construction (IUL) at TU Dortmund University and experts for teaching and learning from the Center for Higher Education (ZHB) at TU Dortmund University run ELLI in a close co-operation. This cooperation ensures that both the technical development and the didactical integration go hand in hand.

The testing cell consists of two different testing machines, a robot and several IT components (see figure 1.). A universal testing machine Zwick Z 250 (right hand side in the picture) is used for tensile or compression tests with forces up to 250 kN. A sheet metal testing machine Zwick BUP 1000 (left hand side in the picture) can conduct different experiments for sheet metals like the Nakajima test (to determine Forming Limited Curves), or a deep drawing test like the cupping test. Both machines have been automated for tele-operative use. Therefore, different components like sensors and actors had been installed. In order to provide the machines with different specimens a KUKA KR 30-3 robot is used for automated specimen handling. Different grippers and concepts were developed to guarantee a safe remote specimen handling. In the following we will refer to the Zwick Z 250’s usage for performing tensile tests. This test is one of the most common and efficient tests for determining material properties. The properties are important for designing manufacturing processes and can be used in forming applications like FEM-Simulations (e.g. simulation of forming processes or production processes). Hence, it is on the one hand a very basic but on the other hand an important test in context of manufacturing technology.

Figure 1: Tele-operative testing cell at TU Dortmund University with two testing machines and one robot for automated specimen handling serving both machines.
For conducting the experiment a user-friendly graphical interface has been developed and integrated into the iLab architecture\textsuperscript{13}. Using this interface it is possible to have access to the equipment, perform the experiment, and download the generated data. For this purpose the web-interface is divided into 4 different areas (see figure 2). In the upper part the user can check and set different parameters affecting the experiment. For example the user can choose between different materials to be tested or different strain rates being applied. Beneath that are, the user can take different actions like “Setting parameters for experimentation”, “Preparing the experiment”, “Start the experiment”, “Pause the experiment”, “Resume the experiment”, and “Cancel the experiment”. Hence, this main control panel is where the user actually interacts with the equipment. The interface’s bottom region again is divided into two areas. On the left hand side, the gained data (applied force on the specimen, the specimen’s displacement, and the current specimen’s width) is displayed as numerical values. In addition to that the user has the option to see the data as a force-displacement-diagram synchronously developing during the experiment. In the area on the right hand side a live video stream of the ongoing experiment is displayed. Here the user can choose between different cameras. For example, the user can see a close-up view of the specimen, the testing machine as a whole or the moving robot.

With the established testing cell and the online interface students can conduct experiments via the Internet without necessarily being physically present in the laboratory. This means that they can be virtually everywhere and only need a computer and a stable Internet connection to perform real experimentation. This approach’s main benefit compared to a video of an experiment is the fact that users can manipulate the experiment by changing parameters and observe to what extend the newly applied parameters impact the results. For the tensile test for example, the user can define the strain rate and the material. In other experiments they can modify up to four parameters. With different experiment setting the users can determine different material properties like the Young’s modulus or the yield strength.

![Graphical user interface for interacting with the testing-cell’s equipment during an ongoing experiment](image)

Figure 2: Graphical user interface for interacting with the testing-cell’s equipment during an ongoing experiment
At the current stage of development, the tensile test is already available to students and professors from all over the world. They just have to register at the iLab server and book a timeslot for their experimentation. Not considering the acquisition expenses (they were fully funded by the Federal Ministry of Education and Research in context with the named project) every experiment only generates low costs for the consumed energy and for the specimen itself. At the moment the stock can be loaded with up to 48 specimens. Considering an average experiment time of 10 minutes the automated testing cell is currently available for up to 8 hours without the necessity to reload the stock. A next extension level will include a stock expansion in order to increase the availability.

Even if this paper does not intend to discuss the general pro and contra of remote laboratories, at this point we want to emphasize that the remote lab’s development for us is not an end in itself. With the current approach several existing needs in laboratory learning can be tackled. No question: Conducting experiments by being physically in a laboratory is a very important experience for students. Our aim is not to replace this experience by just doing online experimentation in the future. Rather our efforts’ main objectives are, firstly, to offer the opportunity doing lab work to more students and, secondly, to introduce live experimentation in other educational settings, e.g. into the lecture. Following this objective and in addition to the remote laboratory’s application discussed in this paper the environment is currently used in face-to-face lectures, too. Therefore, the lecturer is able to run real experiments from the lecture hall with real existing equipment, real material-specimens, real data acquisition, and real trouble-shooting in case of unexpected or unrealistic experimentation results. This is much more than a simulation could ever provide. The remote lab approach is especially interesting for us, as most of our lectures have 30+ or up to 200 attendees. Hence, doing the lecture directly in the laboratory is not an option. With the remote equipment no additional facilitator in the lab is needed to run and show and experiment. Instead the professor himself can perform the experimentation process and link it very closely to the lecture’s content. However, the tele-operative testing cell so far has been integrated into different learning scenarios. One of these settings will be explained more in detail in the following.

The online course

The testing cell so far has been introduced in several educational settings. One of them is a four-week online course taken remotely by students located in different countries. International engineering students take this course before coming to TU Dortmund University for their Master program called “Master of Science in Manufacturing Technology (MMT)” (for more information see http://www.mmt.mb.tu-dortmund.de). The students come from several parts of the world, like Brazil, Mexico, Iran, China, India, and others. Hence, they are from different cultural as well as educational backgrounds. For most of them it is a big step coming to Germany and learning in a fully new and international environment.

The master program has been running for several years now. During the last years it became obvious that some kind of preparation would help these students to make their first steps here in Germany. Therefore, a special online course has been developed, which is available in advance of their journey to Germany. This means that the participating students are not physically at the same location during course participation. Instead, they are still in their home country and join the course online. In addition to the cultural preparation the course offers an ideal opportunity to bring the students in contact with the same laboratory equipment they will be using once they are here in Dortmund. From our perspective alike online education
settings offer ideal opportunities for remote labs’ application, because collaborative labora-
try work at a distance could simply not be realized without this technology. As the online
course is not the main focus for this paper but just the application case, we keep the course
explication rather short and refer for a more detailed information about the course to recent
published publications\textsuperscript{14,15}.

Some explanations on the explicit experimentation task are necessary in order to understand
the context for the evaluations model’s application. We consider it to be very important to
understand the experimentation process not as an end in itself but as one part of the wide
range of engineering activities. Therefore, the students are given a task, in which the exper-
imentations’ results must be applied to a practical case. For this purpose, a superordinate task
has been developed. Within this assignment the students have to calculate the dimensions of
an explicit part of a car body, which prevents the engine from entering into the passenger
 cabin in case of a frontal crash. A predefined stress, which the considered car body part
would suffer in the event of a frontal crash, was given to the students as a starting pint for
their calculations. Furthermore, they need to choose one out of two different material options.
With the help of the remotely executed tensile test, the students have to gain the material
properties for both material options and calculate the part’s resulting dimensions considering
the given constrains. Moreover, they are asked to compare the various material options on
basis of differing material properties and make a statement on different design options (e.g.
rectangular or circular tube). Like all tasks during the course this assignment is done in trans-
national distributed but online connected working groups of 3-4 persons each group.

Summing up, in order to fulfill the assignment the students have to prepare the experimenta-
tion process with respect to an explicit task, execute the experiment (tensile test) by using the
IUL’s remote lab in online connected working groups, and finally analyze the results to solve
the specific case of application. Working and executing the experiment in groups is a very
important aspect in this concept, as the students are experiencing what it means to work to-
gether in multinational groups while being connected just over the Internet. This is the educa-
tional context in which the remote lab is being used and in to which the below explained
evaluation model has been applied for the first time.

The evaluation model

In order to improve the laboratory equipment and the related educational setting the evalu-
ation does not solely focus on the technology and its functionality. Additionally a special focus
should be put on the educational context and the student-computer interaction. Therefore, a
holistic model for evaluating the system and its usage has been developed. In our case this
model is divided into three different perspectives (see figure 3):

1. The individual-perspective (focusing the user’s learning process in the laboratory en-
   vironment),
2. the system-perspective (focusing the technical equipment), and
3. the course-perspective (focusing the lab’s integration into the course context).
With the help of these three perspectives it is possible to have a closer look at the students’
development while using the equipment. At the same time it is possible to pay special attention to the laboratory and its pedagogical integration into the course context. However, for each of the perspectives different evaluation approaches were needed. The aim was to work out both a model serving as a fitting evaluation process for our explicit context and at the same time an adequate approach for other remote laboratory contexts. Hence, we hope that others can adopt the approach and adapt it to their respective learning scenarios. The developed evaluation concept should mainly serve for formative purposes. Therefore, user questionnaires and observations were the most appropriate technique of evaluation. Using these two techniques we had the opportunity to get detailed insights into the user’s opinion about the system and into their personal learning experience. Basically, the evaluation process should answer the following questions:

- Is the intended learning experience successful?
- Is the functional design appropriate to the tasks?
- Does the system do what the user wants it to do?
- Does the learner have problems using the system?
- Does the user like it?
- Does the aesthetic design appeal?
- Is the system regarded as worthwhile to be used again?
- Would the user appreciate more learning applications like this in the future?

In literature on established evaluation concepts for remote laboratories, the following sources could be identified as fitting to our context: Feisel and Rosa (2005)\textsuperscript{17}, Rice University (2015)\textsuperscript{18} Sundararajan and Dautremont (2014)\textsuperscript{19}, Fabrgasa et al. (2011)\textsuperscript{20}, Corter et al. (2011)\textsuperscript{21}, Nilsson (2014)\textsuperscript{22}, Jahnke et al. (2010)\textsuperscript{23}, Garcia-Zubia et al. (2011)\textsuperscript{24}, and Marques et al. (2014)\textsuperscript{25}. Hence, these sources heavily inspired our evaluation model in its three differ-
In addition to that, we decided to primarily make use of online questionnaires\textsuperscript{16}. Therefore, several questionnaires were developed in order to ask the students at different points in time during the experimentation task about their personal competence development and about the experimentation environment. Due to the fact that remote labs are used with a computer and thus online surveys can be done right after the experimentation without media disruption online surveys are the method of choice for our context. In addition to these questionnaires the evaluation model makes use of participatory observations\textsuperscript{16}. Therefore, researchers observe the students while they are remotely conducting the experiments by using the online laboratory equipment. In the following, the different evaluation perspectives will be explained and the respective designed questionnaires will be displayed.

**Individual perspective**

The individual perspective focuses on the students’ competence development during the experimentation. The designed questionnaire refers back the work of Feisel and Rosa (2005)\textsuperscript{17} and Rice University (2015)\textsuperscript{18} and consists of 15 different questions. Especially the developed learning outcomes for laboratory learning posed by Feisel and Rosa (2005) served as an inspiration as they defined general learning outcomes, which can be reached especially by laboratory learning\textsuperscript{17}. For our context we reformulated these learning outcomes and developed questions asking the students to assess their own level of proficiency in the respective area of laboratory work on a 10-point scale from “low level of proficiency” (0) to “high level of proficiency” (10). The following table shows the 15 posed questions (the connected learning outcome from Feisel and Rosa are indicated by the number in brackets):

<table>
<thead>
<tr>
<th>Question</th>
<th>Learning Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. ...handling laboratory equipment, measurement tools and software for experimentation. (1)</td>
<td></td>
</tr>
<tr>
<td>2. ...identifying strengths and weaknesses of engineering specific theoretical models as a predicator for real material behavior. (2)</td>
<td></td>
</tr>
<tr>
<td>3. ...planning and executing common engineering experiments. (3)</td>
<td></td>
</tr>
<tr>
<td>4. ...converting raw data from experimentation to a technical meaningful form. (4)</td>
<td></td>
</tr>
<tr>
<td>5. ...applying appropriate methods of analysis to raw data. (4)</td>
<td></td>
</tr>
<tr>
<td>6. ...designing technical components or systems on Basis of experiments results. (5)</td>
<td></td>
</tr>
<tr>
<td>7. ...recognizing whether or not experiment results or conclusions based on them “make sense”. (6)</td>
<td></td>
</tr>
<tr>
<td>8. ...improving experimentation processes on basis of experiment results, that do not “make sense”. (6)</td>
<td></td>
</tr>
<tr>
<td>9. ...relating laboratory work to the bigger picture and recognizing the applicability of scientific principles to specific real world problems in order to solve them creatively. (7)/(13)</td>
<td></td>
</tr>
<tr>
<td>10. ...choosing, operating and modifying engineering equipment. (8)</td>
<td></td>
</tr>
<tr>
<td>11. ...handling technological risks and engineering practices in responsible way. (9)</td>
<td></td>
</tr>
<tr>
<td>12. ...presenting experimentation results to technical and non-technical audiences in written form. (10)</td>
<td></td>
</tr>
<tr>
<td>13. ...presenting experimentation results to technical and non-technical audiences in oral form. (10)</td>
<td></td>
</tr>
<tr>
<td>14. ...working effectively in a team. (11)</td>
<td></td>
</tr>
<tr>
<td>15. ...applying professional ethical standards in terms of objectivity and honesty in context with data handling. (12)</td>
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</tbody>
</table>

In order to show the students’ competence development this questionnaire had to be answered twice, once before the experimentation and once after the experimentation. In addition to this numerical based self-assessment the second edition of this questionnaire asked for the student’s perceived competence development in context with each of these items. Therefore, underneath each of the questions shown in Table 1 the students were additionally asked the questions shown in Table 2.
Please state if your level of proficiency in context with the above named aspect of experimentation...

• …has decreased since the beginning of the online experimentation task during the course.
• …is unchanged since the beginning of the online experimentation task during the course.
• …has improved by doing the online experimentation task during the course.

Please answer in the comment field why your personal level of proficiency has (not) changed during the experimentation.

System and course perspective
For the system and the course perspective only one combined questionnaire has been designed. The system perspective in this context focuses on questions with regard to the technology and the laboratory equipment. Hence, we were interested in the student’s opinion about the laboratory and its overall usability. The course perspective focuses on the experimentation process and its integration within the broader course context. For the above explained course strong emphasis was put on the students’ collaboration among each other. Hence, questions tackling this interaction were included into the questionnaire. The designed questions were mainly influenced by the work of Sundararajan and Dautremont (2014)\(^{19}\), Fabrigas et al. (2011)\(^{20}\), Corter et al. (2011)\(^{21}\), and Nilsson(2014)\(^{22}\). Finally, the designed questionnaire consists of questions in five different categories (category 1 and 2 focus on the system perspective; category 3-5 focus on the course perspective; see Table 3). The questions in category 1 serve for statistical data about the used technology, here the students can choose between various options. The questions in category 2 to 5 are phrased in form of statements (plus additional fields for comments). For each of these statements the students are asked to rate their personal level of agreement on a 5-point scale from “strongly disagree” to “strongly agree”.

Table 3: Combined questionnaire with focus on system and course perspective

<table>
<thead>
<tr>
<th>Category 1: Platform and device (system perspective)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Which type of device did you use?</td>
</tr>
<tr>
<td>2. Which operating system did you use?</td>
</tr>
<tr>
<td>3. Which browser did you use?</td>
</tr>
<tr>
<td>4. What type of internet connection did you use?</td>
</tr>
<tr>
<td>5. Was this the first time you used an online experimentation environment?</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Category 2: Laboratory system (system perspective)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6. The laboratory system (online platform and experiment equipment) was easy to use</td>
</tr>
<tr>
<td>7. The laboratory system worked without any technical problems</td>
</tr>
<tr>
<td>8. The response time of the laboratory system was adequate</td>
</tr>
<tr>
<td>9. The streamed video was of high quality</td>
</tr>
<tr>
<td>10. The used online platform for the experimentation itself is of high quality and well designed</td>
</tr>
<tr>
<td>• Do you have anything you wish to add in the context of the used laboratory system, that might help us to improve the service?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category 3: Experimentation instruction (course perspective)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11. The objectives of the experiment were clear to me</td>
</tr>
<tr>
<td>12. I was able to fully use the laboratory system by following the instructions in the tutorial video</td>
</tr>
<tr>
<td>13. I would prefer some further help by any tutor in carrying out the experimentation</td>
</tr>
<tr>
<td>14. I understand the connection between the experiment and the given case for the results’ practical application</td>
</tr>
<tr>
<td>15. I was able to acquire all relevant data from the experiment</td>
</tr>
<tr>
<td>• Do you have anything you wish to add in the context of the instruction that might help us to improve the service?</td>
</tr>
</tbody>
</table>
The next step was clear to me in every moment of the experiment and I knew what to do as well as how to do this.

The assigned time slot gave me enough time to fully carry out the experiment.

The video streaming of the live experiment was helpful for me.

I understand how the equipment components (robot, testing machine, measurement technology, camera, ...) being used for the experiment work and how they are connected.

During the experimentation process we worked in groups and I could share what I was doing with my group mates.

- Do you have anything you wish to add in the context of carrying out the experiment that might help us to improve the service?

Performing the experiment helped me better understand the related theoretical concepts (stress-strain diagram, yield strength, etc).

Performing the experiment enhanced my ability to apply theoretical concepts learned in lecture.

This online experiment was a useful learning experience for me.

Such remote laboratory systems are an adequate opportunity to connect students all over the world and letting them carry out experiments.

I wish that online experiments like these could be extended to other cases, contexts or subjects.

On a scale of 0 (very poor) to 10 (very good), how would you grade the online experiment? If it is between 0 and 5, please report the main aspects and issues that you have identified, that lead you to this grade. If it is between 6 and 9, please indicate recommendations so we can reach 10.

In addition to the questions it is important to have a closer look on the questionnaires’ sequencing, as the different questionnaires have different foci. Therefore, the students have to do the online questionnaires using the online software LimeSurvey at different points of time during the experimentation task. Figure 4 shows the sequencing in detail.

As mentioned above the questionnaire with focus on the students’ competence development has to be done once before the experimentation task starts and in an extended version after the whole task is completed. It does not only focus on the students’ experiences with the re-

![Figure 4: Sequencing of the three different questionnaires during the evaluation process]
mote experimentation equipment but also the experiment’s integration into the whole super-
ordinate task. The questionnaire with focus on the technical equipment and the experimental
procedure had to be done right after the remote experiment. That is important as some of the
questions tackle explicit aspects of the experimentation process. Because of that the students’
experiences should be relatively fresh in their minds.

In addition to these questionnaires the evaluation concepts includes a participatory observa-
tion by the teacher for gathering qualitative evaluation data. During this observation, the
teacher can focus on different qualitative aspects like

- the students’ interaction among each other,
- their behavior executing the experiment, or
- technical problems occurring during the procedure.

For the live meetings in the online course we make use of the online meeting Software Ado-
beConnect. We use the same software to build working groups for the experimentation. That
means practically, that one student shares his/her desktop with his/her group mates and the
teacher during the actual experimentation (see figure 5). With this the students can communi-
cate and work together and the teacher is able to easily observe the whole interaction. In the
following we will explain the evaluation results gained during the first application of our
proposed evaluation model in summer 2015.

**Evaluation results**

The displayed evaluation model was developed during summer 2015 and has been applied for
the first time in context of the 4-weeks international online course explained above. The
course was held from August till September 2015. All in all, 16 students took part in this
course. 12 students answered the first questionnaire and 13 students answered the third one
(taking part in this evaluation was voluntarily). In the following we will use the guiding
structure of the three different perspectives to structure our explanations. We will explain the

![Figure 5: Live experimentation using AdobeConnect and sharing the desktop with classmates and teacher](image-url)
individual perspective first and the collectively assessed system and course perspective afterwards. Figure 6 displays the results gained with the help of the 1st and 3rd questionnaire (see Table 1 and 2).

Analyzing the data leads to the following conclusions: First of all, based on their self-perception, all of the students seemed to start into their tasks from a pretty high level of proficiency. The average level of proficiency based on their self-assessment for all of the evaluated aspects was at least 7.3 or even higher.

Comparing the results of the 1st and 3rd questionnaire shows that – even if the average level increased in 8 out of 15 items – completing the laboratory task did not lead to a higher average level of proficiency in each of the evaluated aspects connected to laboratory work. In 2 of the 15 aspects the level remained the same and for some of the items there even can be detected a slight decrease. Namely the self-assessment for the aspects (3), (7), (10), (13), and (15) decreased after the experimentation. This might be surprising at first sight. Looking into these explicit aspects reveals that none of them were in focus during the task’s design. Aspect number (3) for example (“…planning and executing common engineering experiments.”) is without a doubt an important learning outcome in context with laboratory work. However, a detailed experiment preparation by the students is not expected in our experimental setup. Hence, this learning objective is not in focus regarding the current design of the lab and the connected tasks. So why should the level of proficiency improve in this respect? We are aware of the fact, that such a predefined setup supports a common criticism in context with remote laboratories. In many remote laboratories, the experimentation setup is more or less prescribed. Hence, the students do not go the full way from (1) having a practical problem, over (2) defining their research question, (3) working out an experimental setup, (4) doing the experimentation, and finally (5) solve the practical problem. Even if we posed a practical problem and the students had to solve it, we did not ask them to answer a question like “What

![Average students’ self-evaluation for 15 competences in laboratory learning](image)

Figure 6: Evaluation results for individual perspective, based on the students’ self-assessment and comparing 1st questionnaire’s answers with 3rd questionnaire (item numbers correspond to numbers from Table 1; 1 = “low level of proficiency” to 10 = “high level of proficiency”)
kind of experimentation can help to work on that problem?”. Instead we simply posed the assumption that the tensile test is the most appropriate experiment for that situation.

In addition to that, another effect might be provided by the data. Kruger and Dunning (1999)\textsuperscript{26}, Dunning at al. (2003)\textsuperscript{27}, and Krajc and Ortmann (2008)\textsuperscript{28} report that students tend to overestimate their own perceived level of competence before an educational intervention. In such cases experiencing the intervention can lead to more realistic self-assessment scores. For the presented laboratory task in this paper this could mean that the students overinflated their own ability in doing engineering experiments before even knowing about the actual task. During the experimentation they might have recognized that their actual level of proficiency is rather lower than anticipated before. This could be a reason why the reported average level of proficiency in most of the considered aspects did not meaningfully increase and in some cases even decreased. Up to now these are only assumptions on the effects, which are visible in the present data. However, this issue remains unexplained for the moment and further research has to be carried out on these effects.

Nevertheless, the data gives rise to the assumption that the remote laboratory as it is designed now and as it is used in the context of the presented task generally has a positive effect on the students’ competence in engineering laboratory work. Based on the received data in 8 of the 15 items, a positive competence development can be detected. As explained above we additionally asked the students if they think, that their perceived level of proficiency did improve, decrease or remained the same during the laboratory work. The answers in this context are even more supportive. For none of the asked items the students did report a decrease in their perceived level of proficiency. In context with each of the considered aspects of laboratory work at least 50% of the students reported that their proficiency has improved by doing the laboratory work with the IUL’s remote lab. In 9 of the 15 aspects even more than 75% of the students reported that they perceive an improvement with regard to their own proficiency. We take this as a good result for the work done so far and understand it as positive feedback regarding the remote lab’s design as well as for the superordinate task.

The system and the course perspective are evaluated with the help of the second questionnaire (see Table 3). As the first category mainly focuses on technical data and the systems the students used to enter the lab, we will focus on categories 2-5 in the following. However, even within these categories, not every single item will be broadly discussed in this paper. We will highlight the, in our opinion, most important results. The questionnaires’ results are displayed in figure 7.
Figure 7: Evaluation results from 2nd questionnaire (n=11; the numbers on the vertical axis correspond to the items in Table 3)

Category “laboratory system” (see figure 7, items 6. – 10.)
The results show that the technical equipment still offers serious potential for improvement. Especially the statements “7. The laboratory system worked without any technical problems” and “8. The response time of the laboratory system was adequate” provoked considerable disagreement. At this point we include our results gained during the participatory observation. It turned out that the technical setup for this observation as explained above (one student did the experiment, shared his/her desktop via AdobeConnect and the others as well as the instructor watched the process) led to serious problems in the beginning. It was visible that many students, once sharing their desktop with the others, no longer could interact with the experimentation environment’s graphical user interface. As a consequence, the students were not able to click on the buttons for interacting with the laboratory equipment (“prepare experiment”, “start”, etc). Even if we could see them clicking on the respective button in the system, there was no reaction. Even if we haven’t been able to explain this issue completely yet, it seems to be the case that there are correlations between the used browser for the experimentation software and the desktop sharing with AdobeConnect. It may be the case that the desktop sharing option overlays the browser window so that the user no longer can use the user interface. However, using the Chrome browser instead of others like Safari solved this problem and all of the students could successfully do the experiments. As mentioned, this problem hasn’t been sufficiently solved by now but further investigations will be carried out to solve these issues. Nevertheless, the survey results for item 6 and 10 are encouraging. Even if the problematic issues explained above definitely affected the students’ answers, they still consider the laboratory system to be easy to use and of high quality. From our perspective this is a positive result, which gives rise to the assumption that the system will be rated even more positive, as soon as the browser and desktop sharing problems will have been solved.
Category “experimentation instruction” (see figure 7, items 11. - 15.)
Here we would like to especially highlight the results for the items 11, 12, 14, and 15. Item 11 and 14 tackle the question, if the students understand the experiment’s objective and its connection to practice. The presented results are positive from our perspective. To all of the asked students the objectives seemed to be clear, or to put it another way, they (fully) agreed to the respective statement in the questionnaire. Furthermore, only one student (represented by the 9.09%) was uncertain about the connection between the experiment and its real world application. All other students did either agree or fully agree to the corresponding statement. We see this aspect as one of the most important ones in context with experimentation task in engineering education, as the laboratory work is always connected to practice. Understanding the relation to real world is a basis for developing real engineering competence, which is important for future success in the work environment. In addition to that, item 12 and 15 tackle the instruction-based ability to interact with the system. Even though the students again mainly agreed with the statements, there seems to be potential for improvement. Especially the data acquisition seemed to be problematically for two of the students. It might be the case that this was caused by individual problems, as the majority did not report any severe problems. Nevertheless, we will continuously work on that issue to make the procedure easier in terms of a good overall system usability.

Category “experimentation” (see figure 7, items 16. – 20.)
Here the last two items are of particular interest. Giving the statement “I understand how the equipment components (robot, testing machine, measurement technology, camera, …) are being used for the experiment work and how they are connected.”, the results are somewhat mixed. As we understand the linkage between the different components to be important to understand the experimentation setup as a whole, there should be a focus on that for future experimentation. The students at least should know how the equipment as a system works, even if this is not necessarily needed to do the experiment or to continue work with the gained data. Hence, showing the structure and openly discussing it with the students will be included into the experimentation task in the future. In comparison to that, the results on the statement “The experimentation process could be carried out in groups by using AdobeConnect and I could share what I was doing with others.” are positive. The vast majority of the students did fully agree to this statement. This contradicts the presented results in the category “laboratory system” explained above. This inconsistency might be a hint to the fact that the students did not ascribe the occurring technical problems to AdobeConnect but to the experimentation system. However, this result is positive for us, as the students’ transnational interaction and collaboration in context with remote experimentation was one of our foci for the experimentation task’s development in advance.

Category “overall Rating” (see figure 7, items 21. – 25.)
The vast majority of the students fully agree or at last agree with the given statements for the overall rating. Therefore, it can be concluded that doing the remote experimentation helped them to better understand the theoretical concepts behind the tensile test as well as its application in practice. Furthermore, over 90% of the students stated that this task was a useful learning experience. This message is supported by their answers on item 26 (see Table 3). Here the students were asked to rate the online experimentation experience on a scale from 0 (“very poor”) to 10 (“very good”). None of the students rated the experience between 0 and 5, but more than 70% rated it with 8 or 9 points. Moreover, most of the students gave the feedback that such remote experimentation approaches are an adequate opportunity to connect students worldwide for learning and experimentation experiences (item 24). Over 80%
of them even indicated that such online experiments should be applied to other courses, contexts, and cases. This may have been the most encouraging feedback we could hope for.

**Limitations, conclusion and future work**

The study presented above suffers from several limitations. So far we are not able to present more objective evaluation results like student performance in examination or pre-post tests. One reason for this is the fact that the discussed online course, in which the lab is used and evaluated, is not included in the curriculum. It is an optional offer for the students. Therefore, the course does not end with any examination we could use as an objective evaluation method. Hence, we decided at this stage to primarily rely the evaluation on the students’ self-assessment. Nevertheless this is a limiting factor to the study’s results presented in this paper. For future course editions it is planned to improve the evaluation concept by adding more objective methods. For example, it is planned for future evaluation to develop a rubric for assessing the students’ performance during the experimentation. Even if we already had the opportunity to observe the students during the experimentation, the technical problems with the desktop sharing we faced were too severe in the beginning and interfered the observation too much. Once these problems are solved completely and the experimentation task can be done smoothly without any disturbance caused by technical disruptions a sound participatory observation and a rubric-based assessment will be carried out. Furthermore a pre-post test using a quiz on the theoretical content may be designed for future course editions. Another limitation has to be seen in the small number of students that participated in this study. Only between 11 and 13 students took part in the voluntary self-assessment. Of course this has a strong impact on the results significance. That is why we decided not to run any statistical analysis of the data as the possible outcomes could be questioned anyway. However, this limitation can only be solved over time with more students taking part in the course and using the aforementioned evaluation model. Nevertheless, the results we received by applying the explained evaluation model to the online course lead us to several conclusions and indicators for future work at this point.

One important aspect can be seen in the learning outcomes that did not lead to an improved level of proficiency, at least based on the numerical values reported by the students. It will be a task for future course design to have a closer look at these outcomes and to examine why the students partly assessed their level of proficiency even lower after the experimentation. One explanation was given in the text above but other explanations have to be further examined. For example it may be the case that, these learning outcomes are important in context with laboratory work in general but cannot be achieved with the help of remote labs. In comparison to that, most of the students reported a rise in their perceived level of proficiency in all of the intended learning outcomes. This result supports us very much in going further on and reaffirms us regarding our path chosen for the developed remote lab. However, a comparative study with students doing the experimentation online and students doing it while being physically in the lab will be carried out in the future. Therewith, we are looking forward to receive more generalizable results.

Nevertheless, we think that the overall results are positive and encouraging. Except for the technical problems we had using the desktop sharing option and the browser at the same time, the remote experiment equipment worked well without causing any big problems. Hence, the developed remote lab gives us the opportunity to build transnational student working groups, which can do the experimentation collaborating together over a distance. Especially the overall rating by the students is encouraging, as they considered the experimentation experience in general to be helpful and especially useful for understanding the theoretical
background of engineering work. We understand this as the strongest argument to go on with this work, improve the laboratory as well as its pedagogical application and even extend it to other scenarios. However, based on the evaluation results, there is still work to do, especially in context with the graphical interface and the data acquisition. We will continue the work within the coming years, by gaining more data, improving the evaluation model and applying it again to our courses.

With our work we showed a case of application combining two different challenges for future engineering education. One is the development of high quality remote laboratories (in our case for the area of manufacturing technology). This has been extensively discussed above. Another challenge is the improvement of international approaches for education. As the globalization has a strong impact on todays and future working contexts, it will become more and more important to train students for working in international working environments. The development of respective competences must be started at undergraduate level. With our case of application, the remote lab used intransnational online classes, we displayed an approach how to combine education regarding theoretical basics of manufacturing technology and at the same time build transnational groups working jointly together.

As explained above, this was the first time the developed evaluation model had been applied to a practical case. The three perspectives and the questions were easy to use, gave us a good overview and helped us to receive detailed data in different contexts. Nevertheless, looking from a methodological perspective, more work has to be done on the evaluation model. At this stage we cannot say much about the quality criteria objectivity, reliability or validity. Nevertheless, this does not mean that we generally question the received results. Just as explained under limitations, it will be the main work for the near future to deeply investigate the questionnaires’ methodological properness. Up to now we focused on the applicability, which has been proven for our context. In order to evaluate this model more deeply it will be necessary to have more participants doing the experimentation and answering the evaluation questionnaires. This will be put into practice by firstly improving the evaluation model based on the current results, secondly applying it again in the 2016 online course edition, and as a further step, by extending it to other course scenarios. This will guide our future work.

18. Laboratory educators in Natural Sciences and Engineering, Rice University;"Pre-lab self evaluation form", online ressource: http://www.owlnet.rice.edu/~labgroup/assessment/selfeval.htm, last check on 11/12/2015