The Evaluation of Remote Laboratories

Development and application of a holistic model for the evaluation of online remote laboratories in manufacturing technology education

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***Abstract*—The integration of online remote laboratories is still an emerging field in engineering education, especially in the area of manufacturing technology. Over the last years and in different project contexts the Institute of Forming Technology and Lightweight Construction (IUL) and the Center for Higher Education (zhb) at TU Dortmund University developed a laboratory environment, which gives the opportunity to the students to do experiments like the tensile tests–a core experiment for defining material properties–from the computer at home using online technology. This system already has been used in different teaching contexts and its usage is now expanded step by step to other courses. Hence, its practice-based evaluation is coming more and more into focus in order to improve the technical equipment as well as its imbedding into the educational settings. This means that not only the technology and its functionality are evaluated but also a special focus has to be put on the student–computer interaction. Therefore a holistic model for evaluating the system and its usage has been developed. This model divides into three different perspectives for evaluation: (1) The individual perspective focusing the user's learning process in the laboratory environment, (2) the system-perspective focusing the technical equipment, and finally (3) the course perspective focusing the lab's integration into the course context. This evaluation model was inspired by several other evaluation approaches existing in literature. The aim was to work out both, a model that serves as a fitting evaluation process for the explicit context existing at TU Dortmund University and at the same time as an adequate approach for other remote laboratory contexts. This paper presents the evaluation model with its perspectives as well as the used questionnaires and its first application in context of an international online course making use of the IUL's remote lab.**

Keywords—remote laboratory; evaluation model; manufacturing technology; transnational interaction

I. Introduction

With the ongoing development of remote laboratories and its usage in educational settings all over the world [1], [2], [3] the diversity of different approaches for evaluating these labs is growing, too. Looking into these different approaches shows that in some cases the technology itself and its functionality is in focus. In other cases the effectiveness of remote labs for supporting the students' learning processes is more in center of interest.

The same counts for the laboratory environment that has been developed at the Institute of Forming Technology and Lightweight Construction (IUL) in co-operation with the Center for Higher Education (zhb) at TU Dortmund University. This environment was firstly developed, used in teaching contexts and evaluated within 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 at TU Dortmund University was carried out (see e.g. [4], [5]). Moreover, the remote lab's development of and its evaluation always focused not only on the technical issues but as well on the social and pedagogical perspectives [6],[7],[8]. As the remote lab's application scenarios are getting more and more diverse such a multi-perspective approach comes more and more into focus.

Based on the experiences made in PeTEX, the technology was further developed, improved and expanded with additional equipment within another project called "ELLI - Excellent teaching and learning in Engineering Education" (www.elli-online.net). Moreover, a holistic evaluation model has been developed allowing the researchers to work out a comprehensive and at the same time an in-depth analysis of the IUL's lab application.

In the following paper the evaluation model and its first application will be described: In chapter II, some general remarks on evaluation in context with instructional design will be given and various evaluation approaches will be explained. In chapter III, the newly developed evaluation model for remote laboratories in manufacturing technology education will be explained. This model bases on different evaluation methods and different perspectives. In chapter IV, the application case for the evaluation model is explained briefly in order to better understand the connection between the evaluation model and the obtained results. In chapter V, the results itself will be explained. Based on that in the final chapter VI, the results and the evaluation model itself will be discussed from a meta-perspective.

II. Evalaution Concepts and the used methods

According to [9], there exist various evaluation practices and they can be characterized in several ways. In this contribution the authors mainly look at techniques for asking users for their opinions and experiences on interaction and learning with the help of questionnaires (1) and for observing users (2).

A. Asking users their opinions, experiences, and self-assessment

Asking users about their thoughts on a product and how they experience that product is an evident way to get feedback for improving a prototyped system. Such a feedback should answer questions like “Does the system do what the user wants it to do?” and “Does the user like it?”. In context with educational systems the following questions are of high importance, too: “Is the intended learning experience successful?”, “Is the functional design appropriate to the tasks?”, “Does the learner have problems using the system?”, “Does the aesthetic design appeal?”, “Is the system regarded as worthwhile to be used again?”, and “Would the user appreciate more learning applications like this in the future?”

Interviews and questionnaires are adequate techniques for answering such questions. The asked questions can be unstructured or tightly structured. Interviews may also be used to get more details and can be done after the questionnaires in order to build up on their results.

B. General guidelines for designing a questionaire

User questionnaires are deployed to collect the users' opinions, experiences, and for running self-evaluations. [9] depicts a set of basic guidelines for successfully designing a questionnaire. Among these are the following:

- Formulate questions clear and precise
- If suitable, ask closed questions and suggest a variety of answers.
- Consider the choice of questions.
- Keep it simple and evade complex multiple questions.
- Ensure that the assembling of scales is intuitive and consistent.
- A balance must be struck between using white space and the need to keep the questionnaire as compact as possible.

C. Deploying online questionaires

According to [9], some advantages of online questionnaires are the possibility to effectively reach a large number of people, the option to directly convey the data into a database for analysis, the reduced time for data evaluation (as some steps can be done automatically), and the opportunity that faults in the questionnaire scheme can be revised very easy.

D. Observing users

Observing techniques can support identifying user needs important to novel kinds of products and can help to evaluate prototypes. Videos, audio files, minutes, and screen as well as interaction logs are methods to record such observations. Each method has advantages and disadvantages. Recognizable challenges for evaluators are observing persons without disturbing them and analyzing the data, particularly when large quantities of video data are collected. Furthermore, video recording, screen and interaction logging can be analyzed to detect mistakes and inaccuracies, investigate paths through graphical user interfaces and software, or calculate performance time.

Based on the explained evaluation approaches the holistic model for the evaluation of online remote laboratories in manufacturing technology education has been developed. An emphasis in this context has been put on online questionnaires, as this seemed to us as most adequate and effective method for the given case.

III. THE DEVELOPED EVALUATION MODEL

Firstly, it has to be made clear at this point that the use of any laboratory in any educational setting should be integrated into an explicit context or task. This means that the experimentation should not serve as an end in itself but needs a proper context in which gaining the experiment's result is only one part of a superordinate task. Hence, the experimentation's results should be applied in a wider practical context so that the students understand why this experiment and its results are important parts of practical engineering work. This means for the evaluation process that several measuring points are possible. The laboratory can either be evaluated directly after the experimentation execution itself or after the whole task in which the experiment is only one part to be fulfilled. These considerations had a strong influence on our evaluation concept and we finally decided to use various measuring points, based on considerations on different evaluation perspectives (see III B).

In order to work out these perspectives and approaches, several sources on laboratories in educational contexts and existing methods for evaluating online laboratories were examined. These sources served as an inspiration for the development of our holistic evaluation concept (see [10],11],[12],[13],[14],[15],[16],[17],[18]).

A. Evaluation perspectives, methods and the developed questionnaires

Developing a holistic evaluation concept in the given context means not only to focus on the technical part of laboratories. The evaluation of the technical equipment and its correct function are only one aspect. The other is the lab's integration into the given task and its alignment to the course context. However, this is still not enough. As the general aim of educational settings is the development of competences by the learners, their competence development should serve as a third, maybe the most important part. Hence, in order to design a holistic model for the evaluation of online remote laboratories we decided to take these different parts and define them as the three guiding perspectives for evaluation (see Fig.1): (1) The individual-perspective, (2), the system-perspective and (3) the course-perspective. With the help of these three perspectives it is possible on the one hand to have a closer look at the laboratory itself and on the other hand to pay special attention to its pedagogical integration into the course context and the students development while using the equipment.

Talking about methods we decided to primarily make use of online surveys. Therefore, several questionnaires were

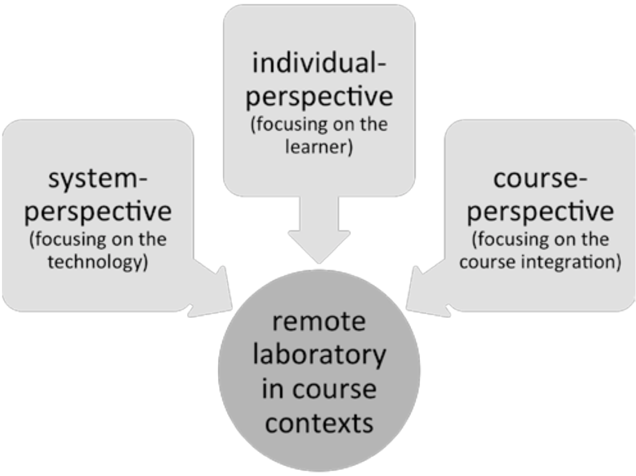

Fig. 1 Three perspectives on remote lab evaluation

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. From our point of view online surveys are the method of choice for our context as remote labs (logically) are used with a computer and thus online surveys can be done right after the experimentation without changing the media. Nevertheless, the developed questionnaires can be used in form of a paper pencil survey, too. In addition to these questionnaires the evaluation model makes use of participatory observations. Therefore, researchers observe the students while they are using the laboratory equipment and making the experiments.

In the following each evaluation perspective will be explained separately. In addition to that the developed questionnaires will be displayed in order to give the reader an impression of the asked questions.

1) Individual perspective

The *individual perspective* focuses on the students and their competence development during the experimentation. Within this perspective, the evaluation should answer the overarching questions "Which competences for engineering work do the students develop during the experimentation?" or "In how far can intended learning outcomes of the explicit experimentation task and the general course context be reached?". Therefore, a questionnaire with all in all 15 questions was developed. It principally bases on the work and approaches of [10] and [11]. By answering this questionnaire, the students are asked to rate their own level of proficiency in different aspects of laboratory work. Each of these items tackles at least one learning objective for engineering instructional laboratories posed by [10] (indicated by the number in brackets). In the following the explicit questionnaire items are shown:

TABLE 1 1st and 3rd questionnaire with focus on *individual perspective*

Please, rate your personal level of proficiency on a scale from "1" (low level of proficiency) to "10" (high level of proficiency) in…	
1.	…handling laboratory equipment, measurement tools and software for experimentation. (1)
2.	…identifying strengths and weaknesses of engineering specific theoretical models as a predicator for real material behavior. (2)
3.	…planning and executing common engineering experiments. (3)
4.	…converting raw data from experimentation to a technical meaningful form. (4)
5.	…applying appropriate methods of analysis to raw data. (4)
6.	…designing technical components or systems on Basis of experiments results. (5)
7.	…recognizing whether or not experiment results or conclusions based on them "make sense". (6)
8.	…improving experimentation processes on basis of experiment results, that do not "make sense". (6)
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)
10.	….choosing, operating and modifying engineering equipment. (8)
11.	…handling technological risks and engineering practices in responsible way. (9)
12.	…presenting experimentation results to technical and non-technical audiences in written form. (10)
13.	…presenting experimentation results to technical and non-technical audiences in oral form. (10)
14.	…working effectively in a team. (11)
15.	…applying professional ethical standards in terms of objectivity and honesty in context with data handling. (12)

This questionnaire has to be completed twice be each student, one time before the experimentation task and one time after the task. This pre post approach opens up the opportunity to compare the students' competence development during the experimentation, based on their self-estimation. In addition to that, the students are asked during the second round of questioning, if they think that their level of proficiency has changed by doing the experimentation for each of the fifteen aspects of experimentation above. Hence, they were asked in the second round of this questionnaire fifteen times (for all fifteen aspects) the following:

TABLE 2 Additional questions for each item for 3rd questionnaire with focus on *individual perspective*

•	Please state if your level of proficiency in context with the above named aspect of experimentation… o … has decreased since the beginning of the online experimentation task during the course. o …is unchanged since the beginning of the online experimentation task during the course. o …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.

2) System perspective and course perspective

These two perspectives were simultaneously tackled in only one questionnaire. Hence, they are coherently explained in the following.

Within the *system perspective* we put a special focus on the technology and its functionality. Guiding questions are among others "Does the technology work as it is meant to and which problems occur?" or "In how far is the environment for experimentation and the user interface user friendly designed?"

The *course perspective* is the last perspective. It puts a special focus on the course context in general as well as its connection to the laboratory work and vice versa. Guiding questions are in this context "Are the instructions given to the students well developed and do the instructions guide the students through the experimentation process?" and–as social interaction is an important course aspect four our explicit context of application (see IV)–"In how far are the students able to collaborate and work in teams during the experimentation?" From our point of view this last perspective additionally can serve as a flexible perspective that might be adjusted to the respective context of application. In our course context a strong focus was put on the students' collaboration. Hence, this can be seen in the questions. For other cases of application other aspects might be in focus and this can be taken into account by respectively adapting the questions to these aspects.

The developed questionnaire in our course context is influenced and inspired by the results of [12],[13],[14],[15]. It is build by 26 questions (plus 3 additional fields for comments) in 5 different categories (category 1 and 2 focus on the system perspective; category 3-5 focus on the course perspective):

TABLE 3 2nd questionnaire with focus on *system and course perspective*

	Category 1: Platform and device
1.	Which type of device did you use?
2.	Which operating system did you use?
3.	Which browser did you use?
4.	What type of internet connection did you use?
5.	Was this the first time you used an online experimentation environment?

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

	Category 3: Experimentation instruction
11.	The objectives of the experiment were clear to me
12.	I was able to fully use the laboratory system by following the instructions in the tutorial video
13.	I would prefer some further help by any tutor in carrying out the experimentation
14.	I understand the connection between the experiment and the given case for the results' practical application
15.	I was able to acquire all relevant data from the experiment
•	Do you have anything you wish to add in the context of the instruction that might help us to improve the service?

	Category 4: Experimentation
16.	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
17.	The assigned time slot gave me enough time to fully carry out the experiment
18.	The video streaming of the live experiment was helpful for me
19.	I understand how the equipment components (robot, testing machine, measurement technology, camera, …) being used for the experiment work and how they are connected
20.	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?

	Category 5: Overall rating
21.	Performing the experiment helped me better understand the related theoretical concepts (stress-strain diagram, yield strength, etc)
22.	Performing the experiment enhanced my ability to apply theoretical concepts learned in lecture
23.	This online experiment was a useful learning experience for me
24.	Such remote laboratory systems are an adequate opportunity to connect students all over the world and letting them carry out experiments
25.	I wish that online experiments like these could be extended to other cases, contexts or subjects
26.	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.

The first category serves to gain statistical data for the laboratory usage. Therefore, in each of the questions in this category the students are given several options they should choose from and indicate the one that applied to their case. Category 2 to 5 served for the actual experiment evaluation. For each of the questions the students are asked to read the respective statement and give their individual level of agreement on a 5-point scale from "strongly disagree" to "strongly agree".

B. Questionnaire sequencing

As explained above the various questionnaires have to be done at different points during the experimentation task. The first one focuses on the individual perspective and has to be completed before the experimentation itself starts in order to assess the students' competences at this point. The second survey focuses on the system and the course perspective. Hence, it should be done right after the experiment in order to assess the technical equipment and the lab's integration into the bigger context. The third questionnaire is an expanded version of the first one and again assesses the students' competences, this time after the completion of the whole task. Hence, it is to be completed at the very end of the whole experimentation

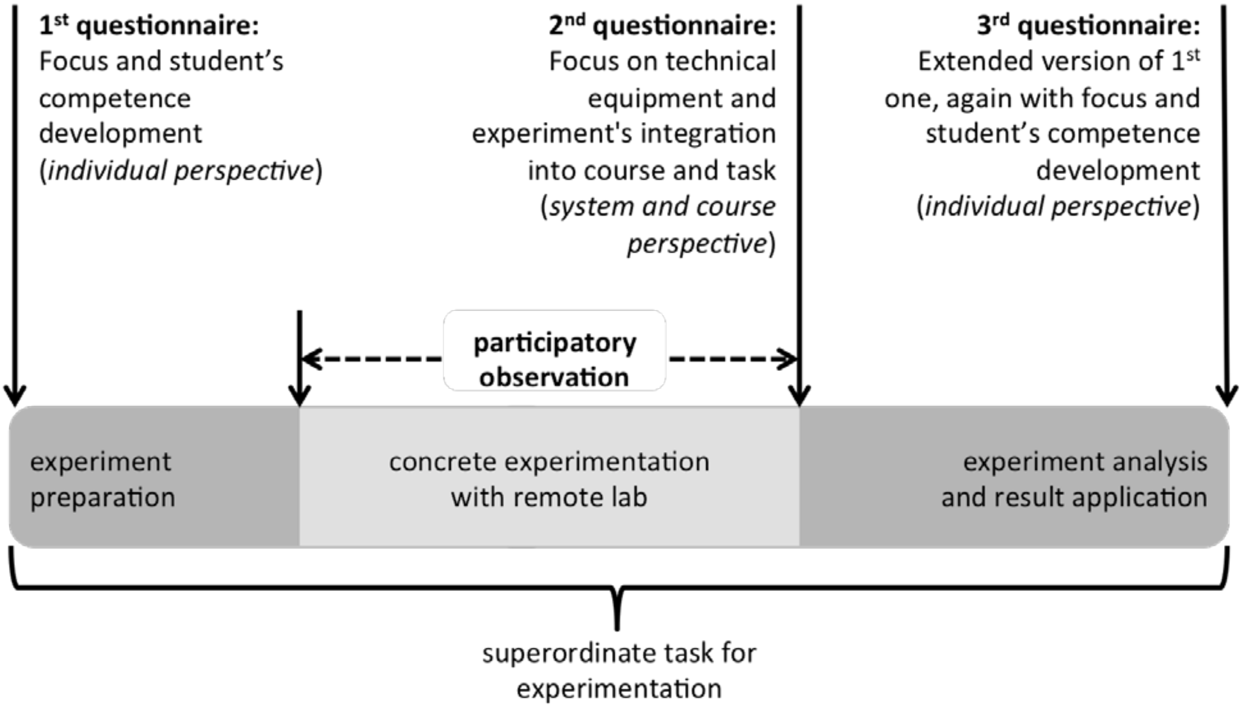

Fig. 2 Sequencing of three different points of measurement during evaluation process

task. This final survey gives the possibility to compare the students' competence development based on their individual self-assessment. As explained at the beginning of A, the evaluation on basis of surveys is complemented by participatory observations during the experimentation. This concept leads to the evaluation sequencing as shown in Fig. 2.

In the following chapter IV the explicit application case will be explained shortly.

IV. Practical Course Context for Evaluation Model's Application

A. MMT Pre Course

The displayed evaluation model was developed during summer 2015 and applied for the first time in connection with an international online course given at TU Dortmund University from August to September 2015. This online course is especially designed for preparing international students doing their "Master of Science in Manufacturing Technology (MMT)" at TU Dortmund University in advance of their stay in Dortmund [19]. Hence, they are taking part in this online course by using different online communication tools before they come to Germany from their home country. One part of this course is carrying out several experiments in teams with the IUL's remote lab, which is mainly represented by a remotely accessible tensile test. This gave us the perfect opportunity to use this course as a first context of application for the newly developed evaluation model described above. For more details on the course itself we would like to draw the attention the respective publications (see e.g. [19], [20]).

B. Superordinate ask for contexting the experimentation

Nevertheless, some words on the explicit task, the students are asked to work on, are necessary in order to understand the context for the evaluations model application. As mentioned above, we think it to be very important to understand the experimentation process not as an end in itself but as one part of engineering activity. Therefore, the students are given a task, in which the experimentations' results are needed in order to go ahead with them. In our case they had to calculate the dimensions of an explicit part of a car body that prevents the engine from entering into the passenger cabin in the case of a frontal crash. Therefore, a defined stress, which the car body part would suffer in the event of a frontal crash, and two different material options (steel and aluminum) were given. With the help of the remotely executed tensile test, the students had to gain the material properties, which were needed in the next steps. Firstly, the students had to calculate the needed part's dimension, which would meet the given constrains. Moreover, they were asked to compare the various materials on the basis of differing material properties and make a statement on different design options (e.g. rectangular or circular tube) for the given car body part.

Summing up, the students had to plan the experimentation 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 for solving the concrete case of application given in the superordinate task.

During the course and the experimentation the evaluation model explained in III was applied. The results will be displayed in the following chapter.

V. Evaluation Results

In the following we will explain the evaluation results in context with the model's first application. For this purpose the three different perspectives for evaluation will be used again, this time as a guiding structure. As the system and the course perspective were commonly focused in one questionnaire, the results will be explained in one joined part. However, we will begin with the individual perspective.

A. Individual Perspective

As explained above, the individual perspective was mainly focused with the first and the third questionnaire, in which the students had to rate their personal level of proficiency on a scale from 1 (low level) to 10 (high level) with regard to 15 different aspects of laboratory work. Table 4 shows the evaluation results based on the students' self-assessment.

TABLE 4 Evaluation results for individual perspective, based on the students' self-assessment and comparing 1st questionnaire's answers with 3rd questionnaire

Please, rate your personal level of proficiency (from 1 = "low level" of proficiency to 10 = "high level" of proficiency) in...			
Average self-evaluation		***Percentage of students rating themselves on a level of 8 or higher***	
1st questionnaire (n=12)	***3rd questionnaire (n=13)***	***1st questionnaire (n=12)***	***3rd questionnaire (n=13)***
(1) …handling laboratory equipment, measurement tools and software for experimentation			
7,9	8,2	75%	77%
(2) …identifying strengths and weaknesses of engineering specific theoretical models as a predicator for real material behavior.			
7,3	7,8	50%	62%
(3) …planning and executing common engineering experiments.			
8,3	7,2	67%	46%
(4) …converting raw data from experimentation to a technical meaningful form.			
8	8,4	75%	85%
(5) …applying appropriate methods of analysis to raw data.			
7,3	8,1	58%	69%
(6) …designing technical components or systems on basis of experiments results.			
7,6	7,9	58%	62%
(7) …recognizing whether or not experiment results or conclusions based on them "make sense".			
8	7,9	75%	69%
(8) …improving experimentation processes on basis of experiment results, that do not "make sense".			
7,3	8	58%	69%
(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.			
7,5	8,1	67%	69%
(10) …choosing, operating and modifying engineering equipment.			
8,2	7,8	83%	77%
(11) …handling technological risks and engineering practices in responsible way.			
7,6	8,2	58%	62%
(12) …presenting experimentation results to technical and non-technical audiences in written form.			
8,2	8,2	75%	62%
(13) …presenting experimentation results to technical and non-technical audiences in oral form.			
7,7	7,5	58%	54%
(14) …working effectively in a team.			
9	9	92%	92%
(15) …applying professional ethical standards in terms of objectivity and honesty in context with data handling.			
8,6	8,5	83%	77%

Analyzing the gained data leads to several conclusions. First of all, it can be stated that all of the students started from a pretty high level of proficiency into the task. The average level of proficiency based on their self-assessment for all evaluated aspects of laboratory work is at least 7,3 or higher.

Comparing the results of the 1st and 3rd questionnaire shows that – even if the average level increased in 8 out of 15 aspects – completing the laboratory task did not lead to meaningful higher average level of proficiency in each of the evaluated aspects of laboratory work. In 2 out of 15 aspects, the level stayed the same and in some of them it can be even seen a slight decrease of this figure. Namely the self-assessment for the aspects (3), (7), (10), (13), and (15) are lower after the task than before. This might be surprising at first sight, but looking into these explicit aspects shows that none of them was in our main focus when we were planning the laboratory task. Aspect number (3) for example ("…planning and executing common engineering experiments.") is without a doubt an important learning outcome in context with laboratory work in engineering education. However, a detailed experiment preparation is not needed in our context as the experimental setup in the remote lab, as it is designed at the moment, is pretty much predefined. Hence, this learning objective is not in focus of the currently designed lab and the connected task. The same counts for aspect number (10) or (13). The latter ("…presenting experimentation results to technical and non-technical audiences in oral form."), in order to explain one more, is also not in focus as the students are not asked to present the results in oral form, but to write a short report on what they found out and how they would solve the given practical case of application. In comparison to that for example aspects (2), (6), and (9) were focused as intended learning outcomes while the task's development. The average level based on the students' self-assessment increased for each of these levels, which is a positive result for us.

In addition to that, another effect might be provided by this data. [21], [22], and [23] 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 before doing the task overinflated their own ability in doing engineering experiments and recognized their actual level of proficiency by doing this task. 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 that might be visible in the data. However, this issue remains unexplained for the moment and more research is to be done on that.

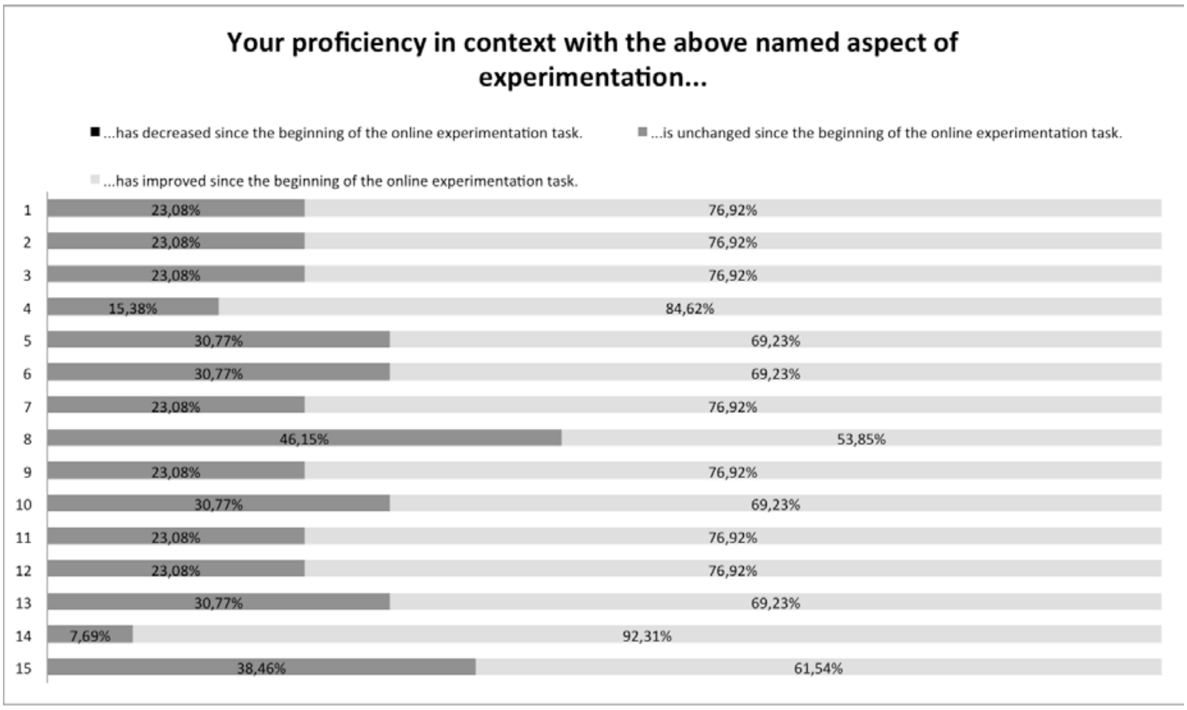

Fig. 3 Self-reported development of level of proficiency with different aspects of experimentation (n=13)

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 leads to a positive effect on the students' competence to execute engineering laboratory work. As explained in III, the presented evaluation model does not only rely on the comparison of the students' self-assessment on their level of proficiency between two points of measurement but also asks directly for their perceived change of proficiency. Hence, we asked the student if they think, that their level of proficiency did improve, decrease or stayed at the same level during the laboratory work. Fig. 3 shows the gained data. The picture that is drawn by these results is much more positive and more clear than looking at the average reported level of proficiency. None of the students reported a decline in the perceived level of proficiency. It is just the other way round, 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 over 75% of the students say that they perceive an improvement with regard to their own proficiency. We take this as a good result for the done work so far and understand it as positive feedback on the designed remote lab as well as the superordinate task.

B. System and course perspective

Following the presented evaluation model, the system and the course perspective are evaluated with the second questionnaire, consisting of 5 different categories (see table 3). For this paper the categories 2 (system perspective) as well as 3 to 5 (course perspective) are of special interest. The first one serves more for internal data acquisition. Hence, the results concerning this category won't be explained in the following (see Fig. 4 to 7). However, not every single item will be broadly discussed here in this paper but the most important results for us will be highlighted. Furthermore, in the following we will include our results from the participatory observation when applicable.

1) Category "laboratory system" (system perspective)

The results in this category show that the technical equipment still offers serious potential for improvement as 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

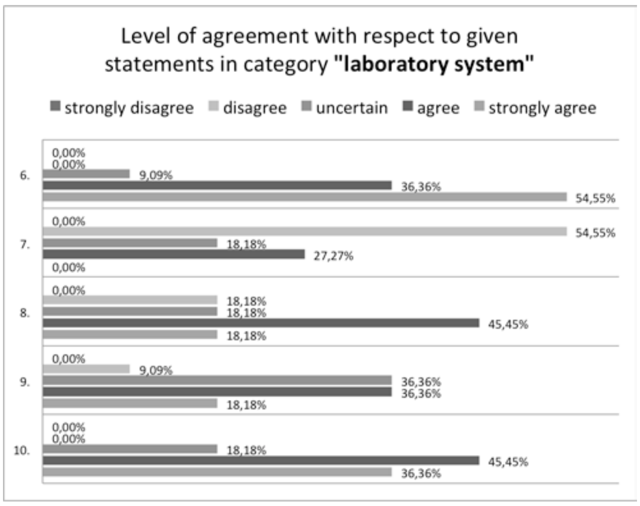

Fig. 4 Evaluation results with respect to the **laboratory system** (n=11; the numbers on the vertical axis correspond to the items in table 2.)

disagreement. At this point we would like to include our results gained during the participatory observation. The technical setup for this observation was the following. In order to do the experimentation in groups one of the students logged into the experimentation environment (using the iLab software of MIT) and simultaneously shared his/her desktop with his class mates and the instructor with the help of the online conferencing Adobe Connect (for more details on the used software setup see [19],[20]). Hence, one of the students could do the experimentation and the other participants could follow his/her steps by watching at his/her desktop. It turned out that this general setup led to serious problems at the beginning. It was visible that many students, once sharing their desktop with the others, no longer could interact with the experimentation environment. A consequence of that was that the students no longer could click on several links for interacting with the laboratory equipment. Hence, they were not able to prepare, start or stop the experiment, even if we could see them clicking on the respective button in the system. These immense problems caused that we had to stop the experimentation session on one day completely and rescheduled them for the next day. Even if we could not 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 Adobe Connect. It may be the case that the desktop sharing options in Adobe Connect overlays the browser window so that the user no longer can use the experimentation software. However, using the Chrome browser on the next day solved this problem and all of the students could successfully do the experiments. As mentioned, this problem is not sufficiently solved by now but more research will be done on this.

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, if the browser and desktop sharing problems are solved, the system will be rated even more positive.

2) Category "experimentation instruction" (course perspective)

In this category we would like to especially highlight the results for the items 11, 12, 14, and 15 (see Fig. 5). Item 11 and 14 tackle the question, if the students on the one hand understand the experiment's objective and on the other hand understand its connection to its practical application. The shown 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 the other students did either agree or fully agree to the corresponding statement. We see this aspect as one of the most important one in context with experimentation task in engineering education, as the laboratory work must not represent a means to an end. Furthermore, the opposite is the case: The real world connection is a basis for developing real engineering

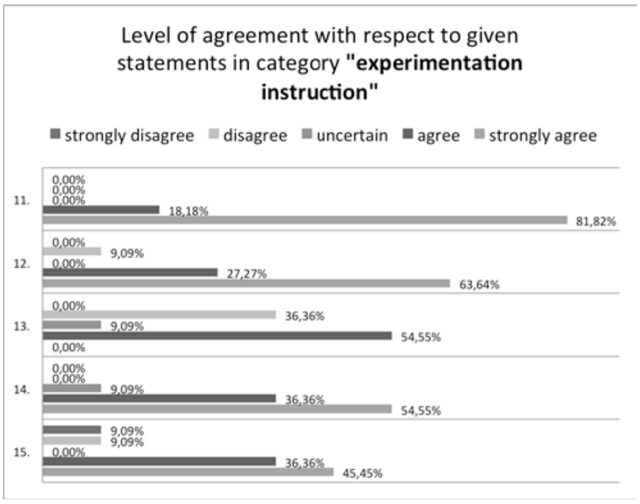

Fig. 5 Evaluation results with respect to the **experiment instruction** (n=11; the numbers on the vertical axis correspond to the items in table 2.)

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 seem 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 because the majority did not report any severe problems. Nevertheless, we will go on working on that and make the process easier.

3) Category "experimentation" (course perspective)

In this category the last two items are of particular interest (see Fig. 6). Giving the statement "I understand how the equipment components (robot, testing machine, measurement technology, camera, …) 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 whole setup, there should be put a focus on for future experimentation. From

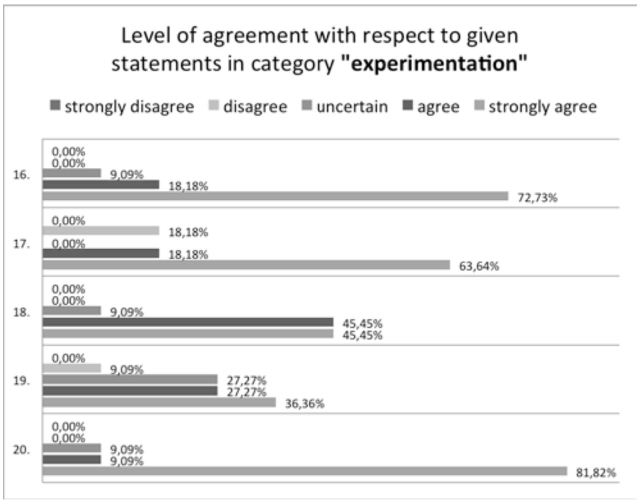

Fig. 6 Evaluation results with respect to the **experimentation** (n=11; the numbers on the vertical axis correspond to the items in table 2.)

our perspective, the experiment must not be a “black box” but the students should know how the internal system structure is put together, even if this is not necessarily needed to do the experiment and work ahead 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 Adobe Connect 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 contradiction might be a hint to the fact that the students did not ascribe the occurring technical problems to Adobe Connect but to the experimentation system itself. 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 and development in advance.

4) Category “overall rating” (course perspective)

This category is the last one in the presented questionnaire and operates from a meta-perspective in order to find out the overall impression the students received during the laboratory task. The survey’s results shown in Fig. 7 are very positive. The vast majority of the students did agree or even fully agree with the given statements. Hence, it can be concluded on basis of their feedback, that doing the remote experimentation helped them to better understand the theoretical concepts behind the tensile test explained in lectures and in advance of the presented experiment 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, in which the students were asked to rate the online experimentation experience on a scale from 0 (“very poor”) to 10 (“very good”). Here none of the students rated the experience between 0 and 5, but over 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 case, contexts, and cases. This might be the most encouraging feedback we could hope for.

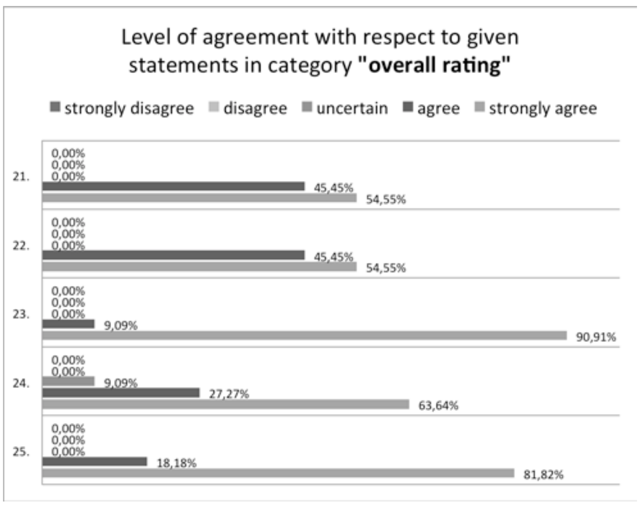

Fig. 7 Evaluation results with respect to the **overall rating** (n=11; the numbers on the vertical axis correspond to the items in table 2.)

VI. Discussion and Future Work

The gained results displayed in V. leads us to three major conclusions:

First of all, we understand the received feedback as mainly positive. Especially the overall rating by the students is encouraging, as they evaluated the experimentation experience in general as helpful and as especially useful for understanding the theoretical background of engineering work. It is somehow surprising that we received such a positive feedback even if some severe technical problems occurred during one of the experimentation session. This leads us to the second conclusion: There is still work to be done on the connection between the experimentation environment and a tool (we used Adobe Connect) that connects students at different places, so that they are able to experience the experiment together. This is one of our major tasks for the future, as we think that such remote labs are not only useful for individual student learning experiences and their experimentation practice but they are also a perfect opportunity to build up transnational learning groups and connect students for doing experiments together. Our third conclusion is, that, based on the students’ self-assessment, the IUL’s remote lab, or better its usage in context with the presented task, does increase the students’ level of proficiency, even if this is not clearly visible when asking the students to rate their personal level of proficiency. More research will be done in the future on the question why in some of the items a decline in the student’s self-assessment could be detected. Nevertheless, asked for their perceived change in proficiency, most of them reported a rise. This result supports us very much in going ahead into the direction we chose with the developed remote lab.

However, there is still work to be done. Firstly, the already discussed problems in context with the used Internet browser and Adobe connect have to be solved. For us this is a critical aspect, as we want to increase the remote lab’s usage for transnational and online connected working groups. Hence, we must find a stable solution to link students to groups via the Internet and simultaneously having them done experiments. Furthermore, there will be done more work to be done on the evaluation model itself. In order to evaluate this model more deeply it is necessary to have more participants doing the experimentation and filling out the questionnaire. On the one hand this will lead to more reliable results for the lab’s evaluation. On the other hand the evaluation model itself can be improved based on a higher number of participants.

Nevertheless, the laboratory system as well as the evaluation model worked well from our perspective. Using the presented questionnaires helped us to receive detailed data. So far not all of the collected data has been evaluated (this especially counts for the data gained during the participatory observation). This also will be a task for the future, too, so that even more results are expected for the future.

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