

The iLab Concept: Making Teaching Better, at Scale

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Lab courses are a great setting to teach. However, to result in a successful learning experience, they often require teachers to spend a significant amount of time. The author reports on how lab courses can be implemented for efficiently supporting learners while significantly reducing the workload of teachers.

ABSTRACT

Lab courses are a great setting to teach. However, to result in a successful learning experience, they often require teachers to spend a significant amount of time. This article reports about how lab courses can be implemented for efficiently supporting learners while significantly reducing the workload of teachers. The presented iLab concept consists of a blended learning teaching methodology and the labsystem eLearning platform that was especially designed for supporting the teaching methodology. Applying the concept results in students and teachers not having to spend time on surrounding tasks that produce overhead, but instead being able to focus on learning and teaching. The iLab concept enables teaching more content in less time. It especially reduces the workload on teachers, making lab courses scale. The iLab concept shows very good learning results with more than 1500 students between 2004 and 2017. The iLab concept was originally developed for teaching students about computer networks and distributed systems. In the meantime, it was successfully used in other domains such as training future teachers.

INTRODUCTION

Lab courses are a great setting to teach. However, to result in a successful learning experience, they often require teachers to spend a significant amount of time.

This article reports on how lab courses can be implemented for efficiently supporting learners while significantly reducing the workload of teachers:

- How can a high amount of knowledge be transferred efficiently for teachers and learners?
- How can students be most efficiently supported in their (self-) learning process?
- How can lab courses become highly scalable?

The presented *iLab concept* consists of a *blended learning teaching methodology*, and the *labsystem eLearning platform* that was especially designed for supporting it.

Together with changing colleagues, including, in historical order, Uwe Bilger, Heiko Niedermayer, Stephan Günther, Benjamin Hof, and Lukas Schwaighofer, the author has been developing the iLab concept since 2004. It has been continu-

ously applied for teaching four computer science courses on computer networks and distributed systems at the Technical University of Munich (TUM) and the University of Tübingen. For details about the curricula see [1, 2]. In 2014 the concept was successfully implemented at the TUM School of Education to prepare future high school teachers.

Until 2017, over 1500 students learned, following the teaching methodology. Their feedback is continuously positive as recent comments exemplify: "Perfectly organized lab course with a good balance of team work, self-study and lecture," "[I like the] syllabus and the way the assignments are organized. The course content, paradigm, and the learning curve," "Good insight into various technologies. Comprehensive exploration of the topics at hand. Nice e-Learning system!"

SHORTCOMINGS OF A TRADITIONAL LAB WORKFLOW

The motivation for developing the iLab concept was a computer networking lab course at the chair of Prof. Carle at the University of Tübingen in 2003. The course was based on the book *Mastering Networks: An Internet Lab Manual* [3]. Its workflow is representative for many lab courses. It starts with a meeting that presents the assignment's topics. Students get printouts including preparatory reading material (*prelab*) and instructions for the hands-on lab. In the following week teams of two to three students meet for the practical part (*lab*) in the lab room. The teams take notes that one team member compiles to a written report afterward. The (paper) journal is handed in together with a digital medium for tool output and so on. Finally, the teaching assistant grades the hand-ins and returns them to the teams.

The described traditional lab workflow has several shortcomings. Important ones that led to the iLab concept are presented and labeled for <s.0> *students* and <T.0> *teachers*.

The *prelab* consists of information that is typically new to *students*. The amount of information and its novelty make it <s.1> *difficult to assess the relevance of the presented material*. The traditional workflow requires high intrinsic motivation as it only provides <s.2> *few motivational elements*. It <s.3> *does not ensure that all team members prepare in the prelab*, resulting in disappointment for

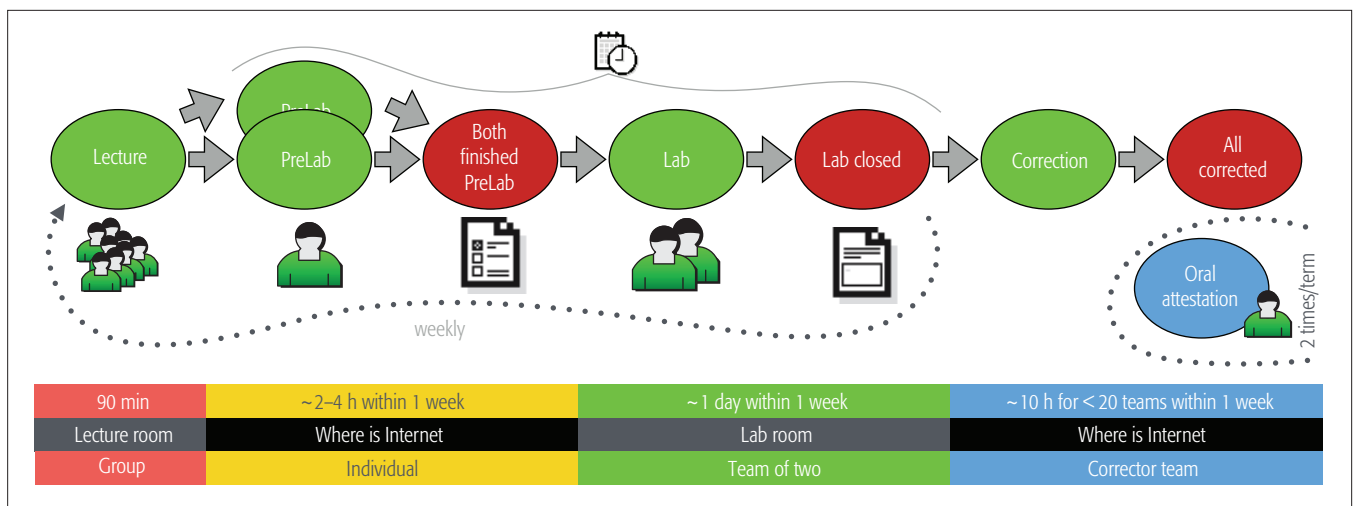


Figure 1. The workflow of an iLab assignment with expected time spans, locations, and settings.

the unprepared students and their team members. Unprepared students have difficulties in understanding the actions of their fellows. Their team members miss valuable support and discussion when solving the exercises together.

In the *lab*, collecting tool output and creating reports from scratch produce *<s.4> significant time overhead*. The time spent on organizational duties cannot be used for learning. Missing tools *<s.5> hinder collaboration between team partners*. The risk occurs that strong team members pull their entire teams through the exercise. As a result, weaker students miss individual tutoring while stronger students miss challenging questions.

<s.6> Remotely exchanging about specific parts of an assignment with team members or teachers is difficult. The medium is unclear. Referring to a certain context is difficult and produces overhead: "in question 3 of section 6.4."

Toward students, the *correction* wants to enable learning from mistakes. Mixed media and the missing context in the answer sheets require *<s.7> high effort to understand and learn from reported errors*. *<s.8> Getting an up-to-date overview on the current personal performance is difficult*.

Manual correction and limited instructor resources lead to *<s.9> significant time distance between handing in a report and receiving correction feedback*. Relating the feedback to a student's own actions becomes difficult.

For teachers it is *<T.1> difficult to get insights regarding the progress and performance of their students during an assignment*. It requires physical presence.

<T.2> Continuously collecting and processing student feedback is important but work-intensive in the traditional workflow. A standard communication channel is missing. Obtaining inquiry contexts consumes time (*<s.6>*).

Traditional hand-ins make *<T.3> the correction of prelab and lab very time consuming*. *<T.3.1> Non-standardized hand-in formats are problematic*. Each team has its own tooling and formatting for the hand-in. Different media are involved including paper, USB sticks, and email. Deciphering *<T.3.2> handwritten hand-ins slows the correction down*. Individual presentations *<T.3.3>*, such

as nice handwriting vs. bad handwriting, *bias the correction*.

Cross-correction helps make the correction fairer since answers of the entire class are directly compared. In addition, *cross-correction speeds the correction up significantly*. Correctors only have to get into the answer context once. The traditional workflow *<T.4> lacks cross-correction support*. When correcting per team, a corrector has to go through the entire exercise repeatedly for each team, including many context switches. *<T.5> Not having the instructions and questions inside the lab report slows the correction down*. It requires switching between instructions, questions, and student reports frequently.

<T.6> Keeping track of the student performance by summing up credits and manually logging the performance takes time.

THE iLAB TEACHING METHODOLOGY

In an ideal world students listen attentively to lectures and interact with their teachers in order to transform presented information into their own knowledge. After a lecture they deepen the learned concepts on their own by reading additional material and discussing it with their fellow students. Driven by the interest to apply their newly obtained knowledge, they meet others to experiment with what they learned. Finally, they are able to reproduce, apply, and extend what they were taught [4, 5]. This last stage ideally lasts for their entire lives.

Often students do not behave as described. However, suitable guidance can help create excellent learners. In a nutshell, the iLab didactic concept implements teaching methods that result in students following the utopian workflow described above and becoming better learners.

The iLab concept fits best for courses that consist of multiple assignments. Students get familiar with the methodology within one to two assignments and learn even better subsequently.

Each assignment follows the same workflow shown in Fig. 1. From left to right, the stages are *Lecture*, individual self-study in the *PreLab*, practical hands-on in the *Lab*, distributed *Correction*, and individual *Oral Attestation*. The bottom of the figure shows the expected time span for each stage, the timeframe a student is allowed to work

The PreLab is entirely done within the specialized labsystem eLearning environment. Students have individual accounts and log in via the Internet. The PreLab consists of learning material that deepens the lecture content. This individual stage allows studying at one's own needs, pace, and depth. To support different experience levels and interests, the PreLab covers diverse aspects of an assignment.

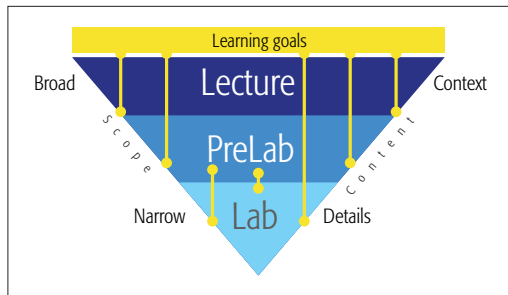


Figure 2. Teaching pyramid of the iLab.

on each part, the location of the activity, and the collaboration setting.

Next, the stages of the iLab concept are detailed with a description, a discussion of the learning theoretical meaning and role within the concept, experiences with the teaching element, and an explanation why and how the element contributes to overcome the challenges identified earlier. The challenges are referenced as *I describe how the challenge is solved.*

LECTURE

An iLab assignment starts with a lecture of typically 90 minutes. Lecture attendance is mandatory because of its important role as the first and last stages of an assignment in the iLab concept.

Figure 2 shows the distribution of learning content to the stages Lecture, PreLab, and Lab. The Lecture starts with a *discussion of the last assignment.* It then covers the current assignment's context including real-world motivations and applications, live demos, group discussions, and best practices for the Lab. It closes with a teaser on the practical part, motivating students to continue working on the assignment.

From a learning theoretic point of view the Lecture fulfills different purposes. The Lecture is either the students' first contact with or a refresher of an assignment's topics [4, 5]. It gives context, framing the assignment and its learning goals [6]. It provides the basic *structure* for reaching the learning goals. The teaching of content related to the learning goals is depicted as vertical lines in Fig. 2. The lines do not always go from the top to the bottom of the flipped pyramid — some teaching formats are more suitable to teach certain aspects than others. For example, software tools are typically only presented in the PreLab and applied in the Lab, while complex application scenarios are better suited for Lecture and PreLab.

The Lecture is the *community event* of the iLab concept. Perceiving oneself as a member of a group that works together enables better learning [7]. The group setting *encourages active discussion* about the learning content.

Interaction is motivating [4]. We stimulate interaction by regular discussion with the group. Typically, two to three meetings where we encourage discussions and create a positive error tolerant atmosphere break the ice, enabling discussion supported teaching. Besides improving the learning experience, the discussion leads to valuable feedback for further improving the learning material. *Continuous improvement* is central in the iLab concept.

The Lecture should be scheduled at the begin-

ning of a week, giving students the rest of the week to continue with their individual preparation.

PRELAB

With the input from the lecture in mind, students have about one week for their individual preparation (Fig. 1). Going through the PreLab typically takes two to four hours. As shown in Fig. 2, the PreLab deepens the assignment's core topics.

The PreLab is entirely done within the specialized *labsystem* eLearning environment. Students have individual accounts and log in via the Internet. The PreLab consists of learning material that deepens the lecture content. This individual stage allows studying at one's own needs, pace, and depth. To support different experience levels and interests, the PreLab covers diverse aspects of an assignment.

It starts with a repetition of the learning goals. This helps students to *identify which are the most relevant parts of the learning material.* Most other prelab shortcomings are overcome by introducing *self-correcting multiple choice questions.*

Knowing the intended learning goals and the upcoming Lab, teachers could point out the relevance of each presented aspect in direct interaction. In the distant eLearning setting *multiple choice questions are placed within the study material.* They *highlight relevant aspects* and *stimulate interaction* with the learning material resulting in *active learning* [4, 5]. An example is asking, after the corresponding reading sections, to which address type a given IPv6 address belongs.

Via the labsystem, students get immediate feedback. Each question allows three answering attempts. The immediate feedback with hints enables learning from mistakes.

The multiple choice questions are a *motivational element.* Students get a score depending on how many tries they needed. This score is only informational since not having to worry about grades fosters explorative knowledge acquisition [5].

Students can see their relative performance in the group (Fig. 3). They can technically only continue with the next Lab stage when their entire team answered all PreLab multiple choice questions. Such gamification elements *increase the motivation* [8]. By looking at the reached scores, teachers get a *timely and accurate overview on the progress of the students.*

For collecting feedback, *the labsystem implements multiple direct feedback channels* including an email form. The coupling with *a support ticket system* increased the timeliness and quality of our feedback notably.

The PreLab has three main roles in the iLab. First, it *fosters active learning* by requiring interaction with and thinking about the learning material. Second, it enables students to *independently reach a similar state of preparation.* Third, the PreLab *ensures that both team partners are sufficiently prepared for the practical part.*

VIRTUAL BARRIER

The practical hands-on is done in teams. To foster success in the practical part, all team members have to be prepared with the necessary theoretical background. For ensuring such preparation

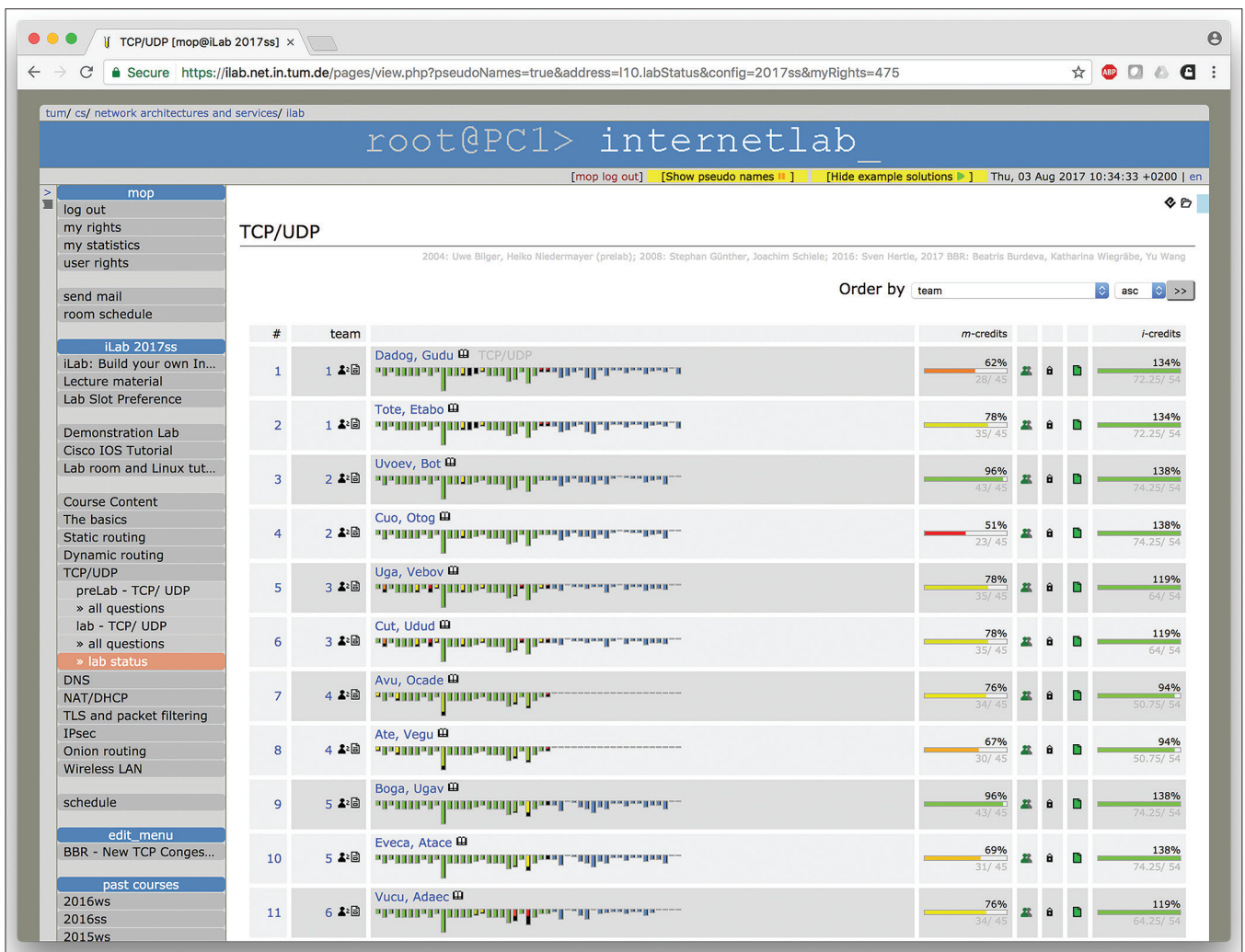


Figure 3. The labsystem.

the *labsystem* provides a virtual barrier: only when all team members have finished all PreLab multiple choice questions can they see the Lab content.

A system-enforced barrier turned out to be highly effective. It is perceived as fair and not questioned. However, with the barrier, the new challenge occurs to prevent cheating by a dumb exchange of answer vectors, *<correct, wrong, wrong>*.

The labsystem prevents such cheating by individually shuffling the order of the multiple choice answers per student. Cheating students now have to communicate the actual answers. Cheating becomes active learning [4].

LAB

Behind the virtual barrier, students see the Lab. The teams get a dedicated Lab workplace called “iLab isle” (Figs. 4 and 5) for an entire day. This enables attending other lectures and so on during a lab day.

The Lab consists of instructions and *<T.3.1> <T.3.2> <T.3.3> questions within the labsystem*. Coming from the book [3], we started having the Lab instructions on paper and the questions online. This media disruption was problematic. Students started guessing the intended activities by only looking at the online questions. As a

result, all content is online now.

Each lab has a real-world story that supports the learning. A complex challenge, such as “We share a flat with five others. Our Internet connection seems to be saturated often. How can we change this?” is solved step by step by the students following the given lab instructions. The continuous story guides the students. Being able to continue tells them immediately that they are on the right track.

The implicit confirmation targets *<s.2> becoming proud and satisfied* of having found a solution to a complex problem. In the case of getting stuck, it allows going back with the insight that things might be different than originally thought. At the end of a lab, all teams have solved all tasks. Still, the quality of their answers differs, resulting in different scores. The *<s.2> complexity of the real-world tasks and the immediately perceived success stimulate the learning*.

The lab is not “tutorial style” but more a “guide at the side” [4] of engineers almost independently solving real-world problems. With enough experience in exercise design, it is possible to provide just enough detail not to get lost while giving students enough freedom to solve challenging problems on their own.

Around 30 questions with free text inputs are part of a Lab story. They allow students to gain



Figure 4. Two students collaboratively working on a Lab.

insights by applying their previously acquired knowledge, and to create new knowledge by solving the challenges. A typically Lab question is, “Why does X not work?” Active learning happens [4, 5].

For the practical part students are paired in fixed teams of two. Both *<s.5> team partners share the free text answering fields* in their lab-system accounts, encouraging cooperation. A *team lock* feature ensures that only one question is answered at one time. This effectively prevents parallel work. Instead, the collaborators discuss the answers to their shared questions, resulting in *active learning*. Ideally, both switch the writer role between each question.

Working in teams is done for different reasons. The team members *support* each other in solving the Lab challenges, enabling *faster progress*. Working with a team partner is *<s.2> motivating and enables collaborative learning*, increasing the learning success [7].

A team size of two is chosen as it is the most interactive setting. *<s.5> Each isle is designed to support exactly two people*. It has two monitors, keyboards, and mice so that both team partners can research material and do configurations independently (Fig. 5). The *<s.5> exercises are designed to provide tasks for both partners*. This prevents team members always taking a passive part throughout an exercise.

During the lab, students *<s.6> <T.2> can send feedback within the eLearning system via tickets and emails*. As for the PreLab, *<T.1> teachers can continuously monitor the progress and get detailed feedback statistics* (Fig. 3).

After answering all questions, a team is done with the exercise. *<s.4> The additional effort of switching between media, and, most important, creating a lab report, is removed*. We use the time gained for teaching more content.

Either students close an assignment or a Lab closes automatically based on its schedule (Fig. 1, top). Like with the virtual barrier students perceive a system-enforced deadline as fair and accept it.

CORRECTION

Enabling fast and fair correction at scale was the

original motivation for developing the lab system. *<T.3> <T.4> <T. 5> <T.6> The correction happens entirely inside the eLearning system. Correctors connect over the Internet*.

The correction starts when all questions of an assignment are closed. This is necessary for *<T.4> cross-correction: correcting per exercise and not per team*. Cross-correction makes the *<T.3> correction faster and enhances the correction quality*.

We apply a four-eye principle with two correction rounds. The first corrector proposes credits, provides feedback to students, and makes comments for the second corrector. The second corrector oversees the proposals and sets the correction visible for the students.

Each corrector is responsible as first and second corrector for a fixed, previously agreed part of an assignment. To reduce biasing effects, beyond having standardized hand-ins, correctors can enable “pseudo names”. The lab system replaces all student names with pseudonyms (Fig. 3). *Standardized hand-ins, distributing the load between correctors, and the anonymization functionality make the correction fair and fast*.

<T.5> The correctors have exactly the same view as the students with the full context of each question. This increases correction speed and quality. Three tutors typically correct 10 teams (20 students) within < 10 hours. The labs typically close on Sundays, and the *<s.9> correction is done until the following Thursday*. To keep this tight schedule, the lab system automatically sends emails to the correctors once a Lab closes.

Having only a short time between answering and getting feedback is ideal for students to learn from their mistakes. The lab system shows credits and corrector comments immediately to students when an answer is set to the status “corrected,” resulting in very fast (partial) feedback. When an entire Lab is corrected, a team receives an automated mail. Getting a timely notification and seeing the corrections directly within the Lab context *<s.7> ease learning from mistakes*.

<T.6> The lab system handles all additional management tasks including summarizing the given credits and informing the students about finished corrections. *<s.8> <T.6> It continuously gives students and teachers detailed up-to-date information about the performance including the currently reached credits*.

GROUP DISCUSSION

An iLab term of 14 weeks has about 10 assignments. Each assignment cycle is followed by a lecture that kicks off the next assignment. The first part of this lecture is dedicated to the previous assignment. Based on common mistakes known from the correction, a discussion is started. We clarify remaining open issues and collect feedback.

ORAL ATTESTATION

Over the term, each student has two individual oral attestations. During the 15-minute attestation, we ask about relevant learning content from the corrected assignments.

The oral attestation has multiple purposes. Regarding grading, it allows distinguishing between both team partners. Regarding the learning, the attestation makes students study the



Figure 5. The iLab laboratory at TUM. Each table is one iLab isle.

topics once again with a time distance. Relevant topics are thereby covered at least four times with Lecture, PreLab, Lab, and learning for the attestation (Fig. 2).

The oral attestations provide a good indication of whether the learning materials reach their intended goals. They allow raising topics again in the Lecture and adjusting the learning material.

MONITORING THE LEARNING SUCCESS

The iLab concept targets efficient self-learning. A major tool is (self-)monitoring [5].

For students, the iLab concept provides various monitoring metrics: the multiple-choice results, the ranking in the group, the discussions with others, the credits from the lab, the correction comments, the discussions in the Lecture, the attestation feedback, and the attestation marks. Teachers can use the same metrics to assess their learning materials and to assess their students.

GRADING

For the overall grading we linearly map the reached percentage in all Lab free text questions to a mark that counts for 60 percent. Each oral attestation counts for 20 percent.

COMMUNICATION

Communication is essential for learning in teams and groups [5]. The labsystem includes several communication channels. Students can send *emails* to other students and the teachers. Links to specific places within the learning material can be included, enabling context-specific exchange. Teachers can use the functionality to contact the students.

The labsystem interfaces with a standard ticket system for channeling the student-teacher interaction, including requesting help from the Lab room, sending inquiries, and giving feedback for improvements. It automatically adds a link to the exact student context to each ticket, making *tutors directly see the corresponding student context*.

We use different ticket categories to prioritize our responses. Help tickets have highest priority, increasing the feeling of *always available support*. Using such tickets significantly increased our answering speed and quality. It made presence in the lab room almost unnecessary, increasing the scalability.

ADDITIONAL LEARNING THEORETICAL DISCUSSION

The iLab didactic concept implements blended learning. It follows a holistic approach covering diverse aspects of learning, including a special methodology, customized tools, and specially designed lab rooms (<https://youtu.be/SPOkrnKQ09c>). Mixing online and traditional classroom settings already affects learning in a positive way [7].

However, compared to regular blended learning offers, the iLab teaching methodology notably increases the variation in teaching. In contrast to traditional professor-up-front lecture setups where knowledge is primarily received and memorized, the iLab fosters knowledge analysis, synthesis, and personal evaluation. The instructors accompany learners [4].

The iLab concept fosters *active learning* [4, 5] by *varying learning modes, settings, and locations*. The different stages of the teaching methodology (Fig. 1) feature different teaching methods. The learning *modes* vary from passive knowledge consumption in a lecture setting toward active application and vital discussion of previously acquired knowledge. Students acquire, deepen, apply, and reproduce knowledge. The learning *settings* are group learning, individual learning, and learning in teams of two. The learning *locations* are a classroom, everywhere with Internet access, and the laboratory.

The iLab concept applies a *constructivist learning approach* [4–6]. It targets active involvement of students [9]. After each Lecture, students create knowledge: They read and reason about possible answers to multiple choice questions in the PreLab, and apply the previously (partly) acquired knowledge to new situations in the Lab. They answer thought-provoking questions in the Lab, actively challenging their new knowledge by discussing it with their team partner. Finally, they have to reproduce and apply it in the oral attestation. [4]

Key tools in the iLab methodology are *continuous repetition* and *constructive alignment* [6]. Constructive alignment in the iLab includes being aware of the learning goals and aligning the teaching methods to them (Fig. 2).

The various forms of presentation and the continuous (self-) assessment guide students to reach the learning goals. The concept points out learning goals explicitly and implicitly via guiding the students, for example, with the content selection, the multiple choice questions, and the frame in the Lab. Instead of repeating the same learning

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The iLab laboratory room.



Using the lab system as a teacher.



Using the lab system as a student.



Labsystem on GitHub.

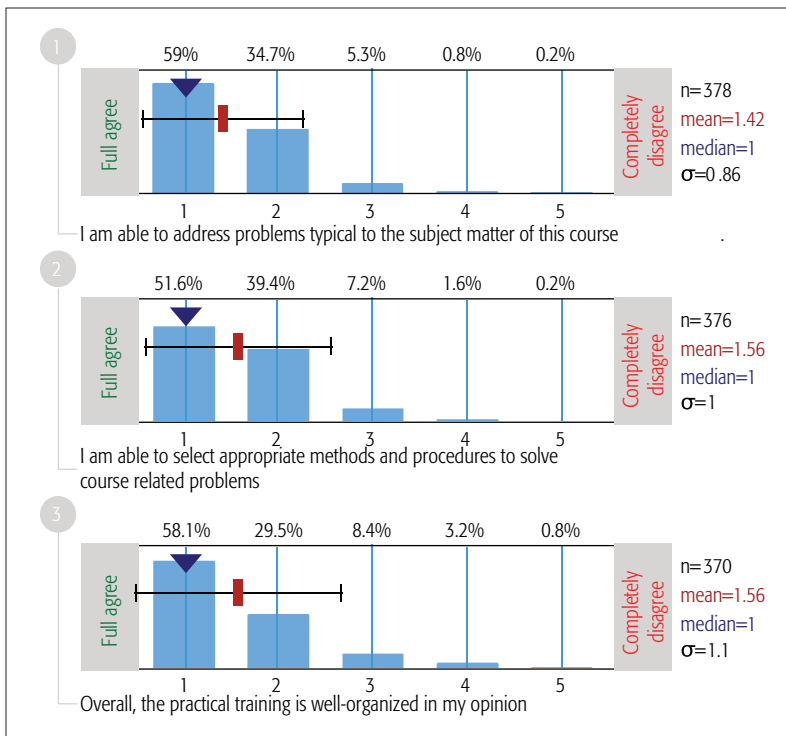


Figure 6. Teaching evaluation results from TUM (2012-2017).

materials multiple times, the iLab concept fosters the *presentation of knowledge from different perspectives*.

Repetition and variation stimulate the interaction with the subjects. The repeated interaction with the learning content from different perspectives stimulates the creation of *cognitive connections*. Ideally such connections are created in or before the first stage, the Lecture. Throughout the other phases of the concept, these connections are ideally strengthened. [4, 5]

The iLab concept creates long lasting knowledge. A student reported that after having been to industry for several years, the iLab content would be among the few things he would still actively remember from university.

THE LABSYSTEM ELEARNING PLATFORM

The *labsystem* is the eLearning system that enables the described iLab concept workflows. The open source system [10] evolves continuously with the teaching methodology.

Unlike in 2004, many eLearning systems exist today. However, they are typically not developed around a specific teaching methodology. Instead, they are general-purpose, such as Moodle (<http://moodle.org/>). Consequently, implementing the iLab concept with them is complex, and results in continuous configuration overhead and usability inconvenience.

Built for the described methodology, the *labsystem* provides native support for the presented teaching methodology. Its core functionality was detailed earlier. Summarizing, the *labsystem* provides content, course, and learning management. The key features that increase the learning experience and enable the iLab concept to scale are barriers, gamification, fixed deadlines, cross-correction, tickets, and course management. Figure 3 shows the course management functionality with

detailed student results for an assignment.

Differentiating features compared to other existing eLearning systems include the virtual barrier, the tight integration of a ticket system, automated email sending, and privacy-aware data handling including anonymization, decreasing the correction bias.

A video on how the *labsystem* is used by students and teachers can be found in [11, 12] together with many video tutorials.

EVALUATION

An important part of the iLab concept is continuously collecting feedback. The quotes in the introduction are exemplary of the continuously encouraging feedback.

Until 2017, more than 1500 students participated in courses applying the iLab concept. These courses are competing for students with other offers. The relatively high number of participants indicates the popularity of the concept and the topics.

At Technical University of Munich the iLab courses participate in the faculty-wide teaching evaluation. Figure 6 shows results from the past five years. The diagrams show the feedback to the questions:

- I am able to address problems typical of the subject matter of this course.
- I am able to select appropriate methods and procedures to solve course-related problems.
- Overall, the practical training is well organized in my opinion.

The histogram bars show how the student votes are distributed. The sample size (n) is given on the right. The arrow shows the median, the thick indicator the mean, and the candles the standard deviation (σ) to each side of the mean.

The very good results in the first two questions show that the teaching methodology is successful. Central didactic goals of a lab course are reached. The third question explicitly asks for the organization of the course where the iLab concept is a major part. The answer shows that the iLab concept provides high-quality teaching.

CONCLUSION

The presented iLab teaching methodology improves the learning success in university lab courses, while it significantly reduces the workload on teachers. The iLab concept enables learning by doing in a way that turns out to be fun for the students and very efficient for teachers. The described use of blended learning allows focusing on content, while the described methodology ensures high-quality, time-efficient teaching. Established workflows are used, and most of the organization is automatically done by the *labsystem*.

The online parts of the *labsystem* introduce high flexibility for learners and teachers. The concept's workflow support enables even inexperienced teachers to create high-quality teaching experiences.

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BIOGRAPHY

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